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Morse, Frank Lincoln

Power, its application from the 17th dynasty to the...

Ithaca, N.Y.

1923

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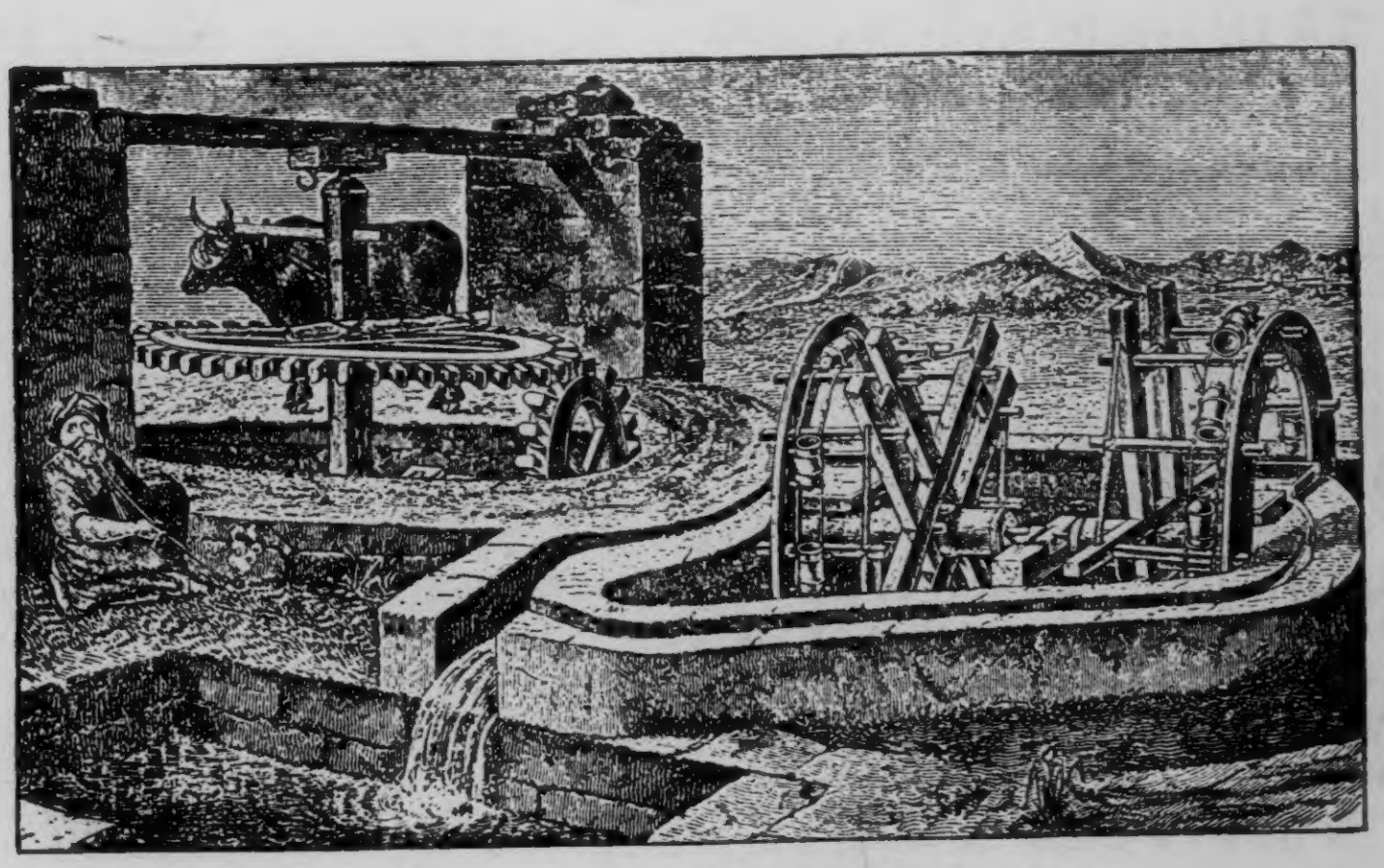
Power

Its Application from the 17th Dynasty to the 20th Century

Address by F. L. Morse, 26th Annual Convention, American Mining Congress, Miiwaukee, Wis., September 27th, 1923



Jcseph's Well, 1400 B. C.

Ithaca, N. Y.

Morse Chain Company

1923

FOREWORD

FROM the beginning of history, the growth or degree of civilization of a race or nation can be determined by their development and application of power transmission and the utilization of the sources of power, the strife and rivalry between races and nations and the development of the instruments and arts of warfare compelling their engineers to look for higher and higher efficiency and improve methods for increasing of production.

In connection with the history of the Evolution of Power transmission, it is noticeable that invariably the rise and fall of races, empires and nations, followed the improvements and inventions for the utilization of power in mining, manufacturing and transportation.

The records that have been left of the methods of mining and production used in ancient times can only be found through a few hieroglyphics, sketches, bas-relief on pottery and from the writings of the philosphers of the times. It is remarkable how few of these make any reference to mechanical arts or processes or the power used but we can consider the following sketches and references as representative of the knowledge of several periods.

Today the United States with less than 10% of the world's population, produces and employs in its factories, mills and mines nearly one-half of all the power now utilized in the world.

Cps Nov. 14 1923.

THE EVOLUTION OF MECHANICAL DEVICES AND POWER TRANSMISSION

IN ANCIENT EGYPT

THE history of power and power transmission is of the deepest interest because the great revolutionary changes in civilization, have most of them been caused, or at least made possible, by improvements or its transmission and application.

The first records of civilization come from Egypt. According to the ancient Egyptian lists of dynasties and kings, the dawn of history there may go back more than six thousand years, but a few Egyptian astronomical records have led some Egyptologists to place the date of the 1st Dynasty about 5900 years ago.

Under the Old Kingdom of Egypt which extended from the 1st to the 6th 3900 B. C.-2800 B. C. Dynasty, there was only one power, with the exception of muscular strength, which was applied to anything which might be considered a machine. This power was the wind, and the machine was the sailboat. Rude sketches on pottery indicate that the sailboat was as old as the 1st Dynasty, 3900 B. C. and there are beautiful representations of it in the tombs dating from the 4th to the 6th Dynasty.

FIG. 1—The Egyptian shadup used for irrigation, 3000 B. C. From a tomb painting.

When it is remembered that Egypt was a narrow valley stretching for thousands of miles along the Nile, and that water transportation was the one great means of intercommunication, it will be realized how important the rowboat and sailboat were to Egyptian civilization.

Egypt was irrigated and fertilized by the annual flood of the Nile, but since much of the land that was cultivated was above the flood, and since there was almost no rain, the Egyptians had to develop a system of irrigation.

A machine in use for this purpose was the shadoof which is pictured in the tombs of the Old Kingdom. It was much like the well sweep to be seen in country districts, and consisted merely of a pole hung on a post in such a way that it could be swung easily up and down, or around. One end of the pole was enough heavier than the other to overcome the weight of the bucket when it was filled with water or dirt. This was the first crane, and went far to make possible the cultivation of the valley of the Nile.

The Egyptians believed that the soul would live as long as the body continued to exist. Therefore they mummified the body, and built rock tombs and immense pyramids to preserve the mummy. A machine which was of the greatest assistance in cutting out the huge stone was the bowdrill.

FIG. 2—The Egyptian bow drill, from a tomb painting. 3000 B. C.

The bow went back to prehistoric times, and was one of the first inventions which won man supremacy over animals. In drilling, the cord of the bow was wrapped around the drill, over the top of which was placed a hand piece by means of which one hand held the drill in position, while the other turned it by running the bow back and forth.

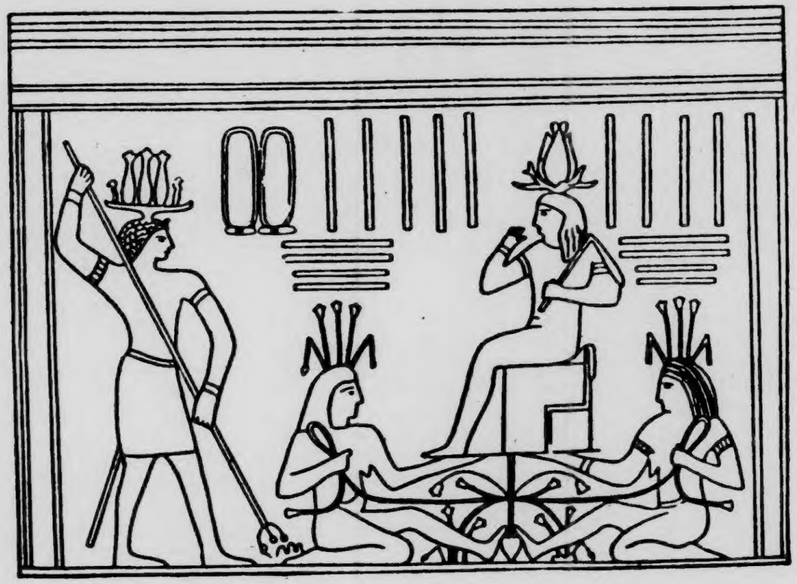


FIG. 3—A symbolic representation of the rope drill. Egypt, about 1500 B. C.

The bow drill was used both for making fire, and for work in wood, stone, and metals; and, we may add, continued to be used for drilling until the end of the 18th Century.

In the bow drill we have the first machine using some form of rope transmission, but of course the Egyptians used ropes for many other purposes, such as towing boats, managing sails, and hauling drags.

Pictures of that period show heavy drills for quarrying being worked by two men at once. For this method the cord was wrapped around the drill without the use of a bow. In one picture the workmen are represented sitting on one foot, while with the other they hold the drill in place. One overseer adds weight to the drill by sitting upon it; while another prods the foot of the workman with a trident. This picture is symbolical, for the necessity of two workmen at such a drill caused it to be used as an emblem of cooperation, and of the union of Upper and Lower Egypt.

The Egyptian ropes were made from raw-hide, papyrus, or flax. A picture of the Old Kingdom shows a rope maker having a weight fastened to the rope so that it could be swung around to assist him in giving the twist.

The great stones were transported from the quarries to the river placed on barges, and again hauled from the river to the site of the pyramid or other building. Just what power or means was used in these tremendous operations is uncertain. It is practically sure that smooth roads were constructed from the quarries to the Nile, and from the Nile to the pyramids. The roads leading up to the pyramids were inclined planes, for remains of them are still extant.

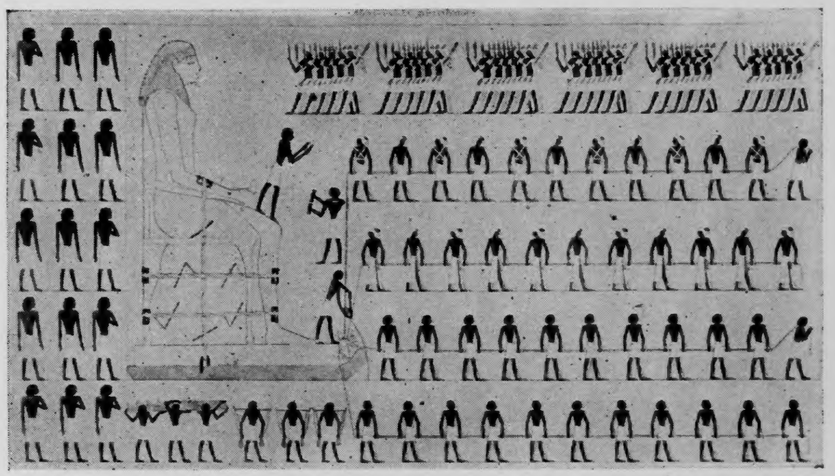


FIG. 4—Egyptian transportation of a statue. About 4000 years ago.

A picture of the 12th Dynasty 2400 B. C. shows a great statue fastened to a drag which is being hauled along by a large number of men. A man on the front of the drag is pouring oil on the road to make the drag slip more easily, while workmen carrying other oil pots are depicted at the side of the drag. A foreman standing on the knees of the statue is clapping his hands so that the men will pull in unison.

It is noteworthy that no ancient Egyptian pictures represent the employment of pulleys, rollers, or levers. In the rigging of the sailboats, the ropes ran through simply rings. It is even doubtful whether the Egyptians used wheeled vehicles until after the 12th Dynasty, when they were imported from the East.

Other machines pictured in the tombs from the 4th to the 6th 2700 B. C.-2100 B. C. Dynasty include the potter's wheel, the spindle, the hand loom, and the blow pipe; to say nothing of such implements as the plow; and such tools as the plane and saw.

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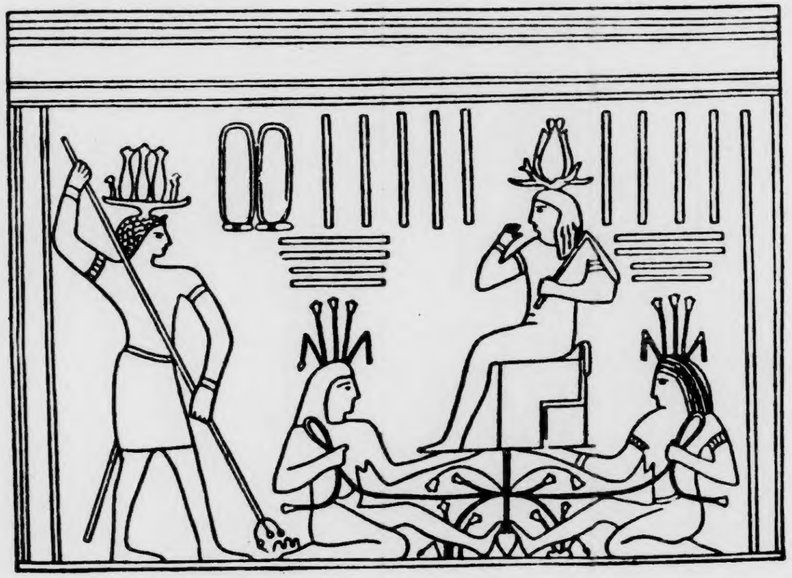

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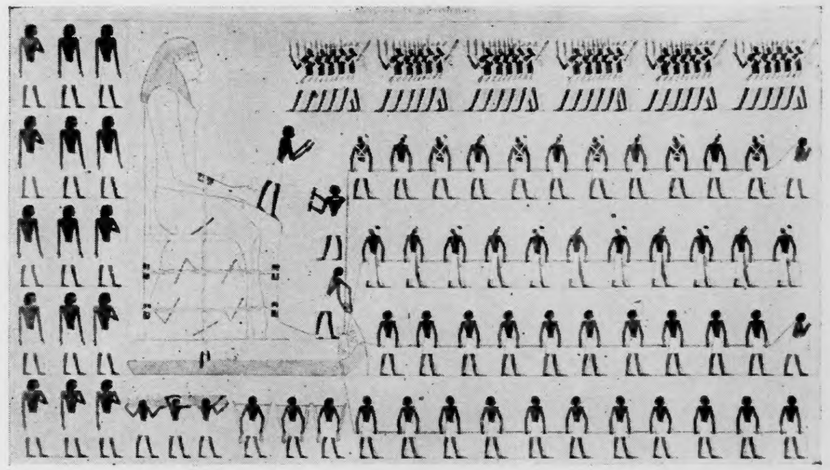

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After the 12th Dynasty Egypt was overrun by the Hyksos or Nomadic kings. During this invasion the horse and chariot were introduced, and perhaps accounted for the success of the invaders. At the end of the 17th Dynasty the Nomadic kings were driven out, and the New Empire established at Thebes about 1600 B. C.

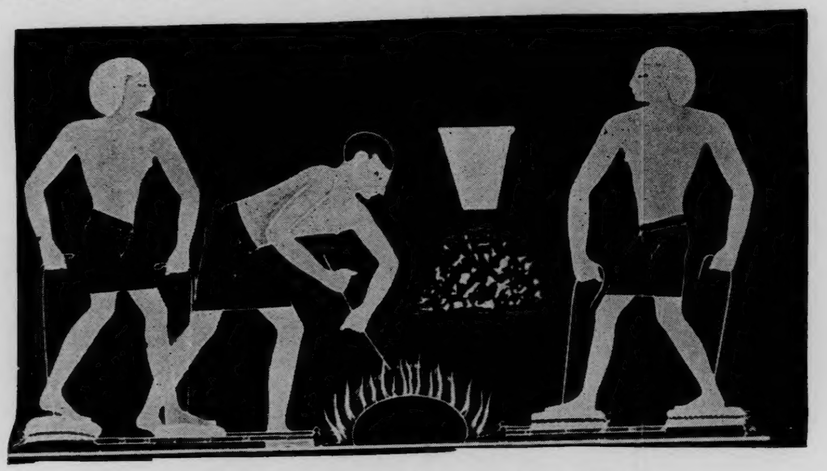

FIG. 5—The Egyptian foot bellows. About 1500 B. C.

The most important new machine depicted in the tombs of the New Kingdom was the foot bellows. This consisted of two goat skins with hollow rods leading from them to the fire. The workman stood with one foot on each skin, and by resting his weight on one foot drove the air from that skin into the fire, while he pulled on a cord to raise and fill the other skin.

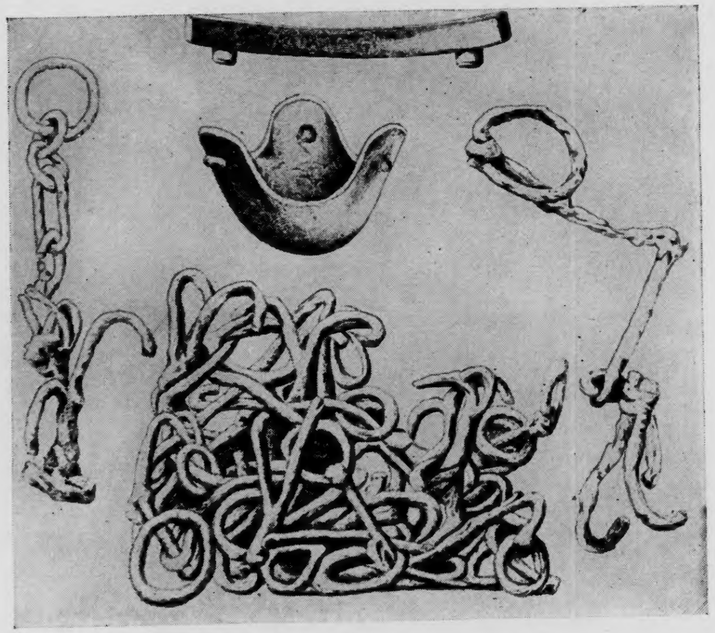

FIG. 6—Assyrian chains, 8th century B. C.

Another example of the use of air is a highly interesting picture of the same period. This proves that siphons were already employed for drawing off the contents of large jars. Thus the Egyptians knew something of the properties of air twelve hundred years before the Alexanderian philosophers.

The foot bellows enabled the Egyptians to melt the softer metals easily, and even to smelt iron. Bronze was used in quantities, but iron only in a small way, though both metals were cast as well as forged. There is no evidence that the Egyptians made chains until late in the Theban Empire, though it may be remarked that many forms of links were developed for ornamental necklaces.

The earliest iron chains thus far discovered are those found by Place in the palace of Sargon, at Khorsabad, dating from about 720 B. C. The chains are rather heavy, and consist of simply circular links.

One rather surprising advance was the use of the bow to drill several holes at once. The cord was wrapped around each drill separately, but the workman had to exercise considerable skill to keep the drills in position.

IN SOUTHWESTERN ASIA

The wheel,—one of the commonest mediums for transmitting power,—seems to have been invented in southwestern Asia. An archaic Babylonian cylinder seal which is sometimes dated earlier than 3,000 B.C., represents a deity seated in a cart which has four wheels and is drawn by a dragon.

The victory stele of Eannatum of Lagash, about 2900 B.C., represents the king riding in his chariot, but the stele has been broken, and little remains of the vehicle. How effective the wheeled chariot was in conquering nations which lacked it, may be gathered from Judges, Chapter I, where we read: "And the Lord was with Judah; and he drove out the inhabitants of the mountain; but could not drive out the inhabitants of the valley, because they had chariots of iron."

FIG. 7—Drawing water to the top of a fort.
An Assyrian pulley, 9th century B. C.

The pulley, also, was probably first developed in southwestern Asia. The earliest known record of one is a sketch on a slab found by Layard, in the palace of Shalmaneser II, at Nimrud about 860 B.C. It represents a single pulley employed for drawing water from the river to the top of a fort.

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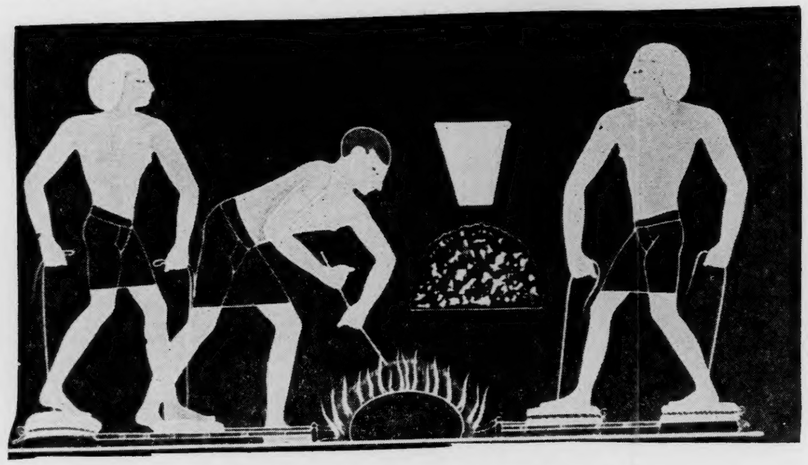

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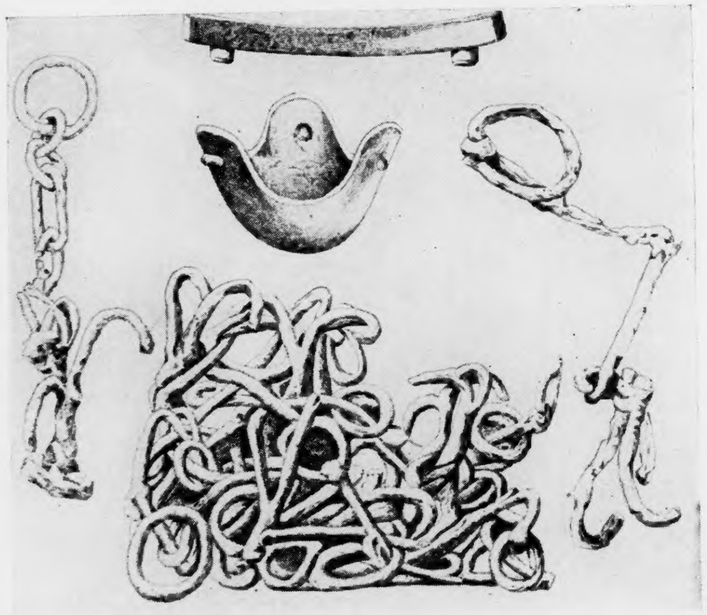

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A series of bas-reliefs discovered by Layard, at ancient Nineveh, and dating from the reign of Sennacherib, about 700 B.C., depicts levers and rollers being employed to help transport a large statue. It is hauled by long lines of men without the use of pulleys.

In the same series of bas-reliefs, workmen are shown building a mound by carrying up the dirt in baskets on their backs without any mechanical aid. These workmen were probably captives or slaves, as they were driven by rods in the hands of foremen.

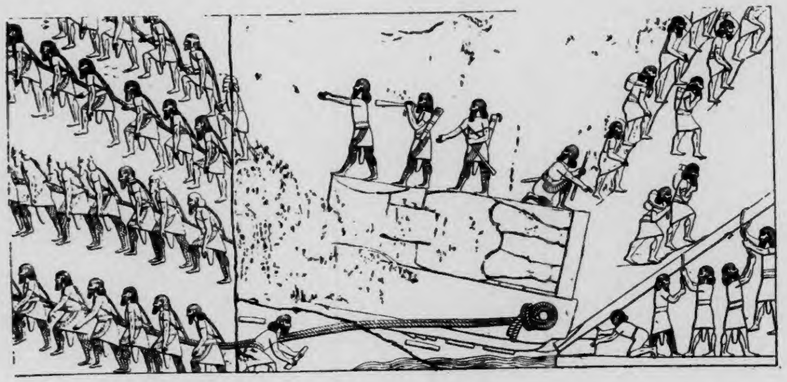

FIG. 8—Assyrians using the lever, wedge, and rollers, about 700 B. C.

The necessity of irrigation along the banks of the Euphrates and Tirgris led to the early development of machines for this purpose. Shadoofs much like those of Egypt are pictured in a bas-relief found at Kuyunjik, and dating from about 700 B.C. They are arranged one over another in order to raise the water to successively higher levels.

Strabo wrote that at the side of the steps mounting to the hanging gardens of Babylon were water engines, by means of which workmen assigned to the task labored constantly in raising the water from the Euphrates.

The Persians were using capstans before 480 B.C., for Herodotus says that the engineers of Xerxes in building the second bridge across the Hellespont used capstans to draw the cables of flax and papyrus.

AMONG THE ANCIENT GREEKS

Only fragments remain from the ancient Greek writings on mechanics, but even they are sufficient to prove that, experimentally at least, important advances were being made.

An interesting use of the bellows in the Siege of Delium, 424 B.C., is mentioned by Thucydides. At one end of a long pipe the Boeotians hung a vessel full of burning charcoals, sulphur, and pitch. This was placed against the wooden fort, and a large bellows was used to blow through the pipe and scatter the burning materials against the wall.

Aristotle, 384-322 B.C., in his Mechanical Problems, discusses the principles of the balance, lever, oar, rudder, sail, wedge, roller, pulley, multiple pulley, whirlpool, and colonion or shadoof. In a somewhat transcendental way, he reduces most of their principles to the properties of circles. He mentions the action of wheels of different sizes, whose circumferences touch, but says nothing directly concerning wheels with teeth or cogs.

Aristotle mentions that pulleys were then used by builders to raise heavy materials.

Battering rams had been in use by the Assyrians, but were much improved by the engineers of Philip and Alexander the Great. One form of ram, which was employed by Diades, who served under Alexander, had a ram enclosed in a pipe

fifty cubits long, and one cubit in height. The ram was worked by windlasses, and "there were numerous rollers enclosed in the pipe under the beam, which made its movements quicker and stronger."

This is perhaps the first mention of roller bearings as an integral part of a machine.

The catapults depended for their strength upon ropes which were very tightly twisted by means of wheels.

Interesting accounts of the machines invented by Archimedes, 287-212 B.C., for Hiero of Syracuse, are given by Polybius and Plutarch.

Archimedes was educated at Alexandria, in Egypt, which was then under the Greek Ptolemies. His fame led Hiero I, who was a relative, to invite him to Syracuse. Archimedes there gave a demonstration of the capabilities of machinery "by drawing a ship from the drydock in a straight line, as smoothly as if she had been on the sea, by merely holding the head of the pulley in his hands and drawing the rope by degrees."

Hiero I thereupon persuaded Archimedes to construct for him various war machines which were not used during his reign, but were directed by Archimedes when the Romans beseiged Syracuse 215-212 B.C.

He had catapults wound with different degrees of tightness, so as to throw different distances.

When the Roman ships tried to attack the walls by means of towers 'he had engines ready all along the walls, not visible at other times, but which suddenly reared themselves above the wall from inside, when the moment for their use had come, and stretched their beams far over the battlements, some of them carrying stones weighing as much as ten talents, and others great masses of lead. So whenever the towers were approaching, these beams swung around on their pivot their required distance, and by means of a rope running through a pulley, dropped the stone upon the vessel."

Against storming vessels, Archimedes "let down an iron hand swung on a chain, by means of which the man who guided the crane, having fastened on some part of the prow where he could get a hold, pressed down the lever of the machine inside the wall; and when he had thus lifted the prow and made the vessel rest upright on its stern, he fastened the lever to his machine so that it could not be moved; and then suddenly slackened the hand and chain by means of a rope and pulley."

Thus many of the vessels were plunged into the sea, or capsized and made useless.

Galen, the Roman physician, stated that Archimedes employed a burning glass to ignite the Roman ships.

Archimedes is said to have invented the water screw to remove water from the ships of Hiero II. His various other discoveries lie outside of our field.

Another great inventor of Alexandria was Ctesibius, who lived about 250 B.C. He was the son of a barber, and arranged a metal mirror in his father's shop so that the weight of a leaden ball running through a small pipe would make it fly back in position after being used. The ball fitted the pipe so closely, that in falling it suddenly forced out the air and produced a sound. Starting from this, Ctesibius substituted water for the ball, and constructed the first mechanical organs which were operated by water.

He applied the same general principle of compressed air to the construction of hand bellows, and experimental air gun, of the syringe, and of the forcing pump.

He invented also a water clock in which he used toothed wheels. In it, according to Vitruvius, was "a rack and revolving drum, both fitted with teeth at regular intervals, which, acting upon one another, induce a measured revolution and movement."

The shut-offs for regulating the water consisted of two cones, one hollow and the other solid, and both of them, according to Vitruvius, turned on a lathe so that they would fit perfectly.

The forcing pump likewise included pistons and valves which were carefully turned by means of a lathe. The lathe used for the purpose was the old Egyptian bow drill, which was set horizontally instead of vertically, but still worked by menas of a bow.

A pupil of Ctesibius was Philo of Byzantium, who probably lived about 225 B.C. Only a few fragments are extant concerning him, but they credit him with the development of several practical machines of the greatest importance. Philo's sketch for raising water by an undershot water wheel driving by endless chains from wheels at each side an overhead shaft having a three sided sprocket carrying endless link bars with buckets suspended between.

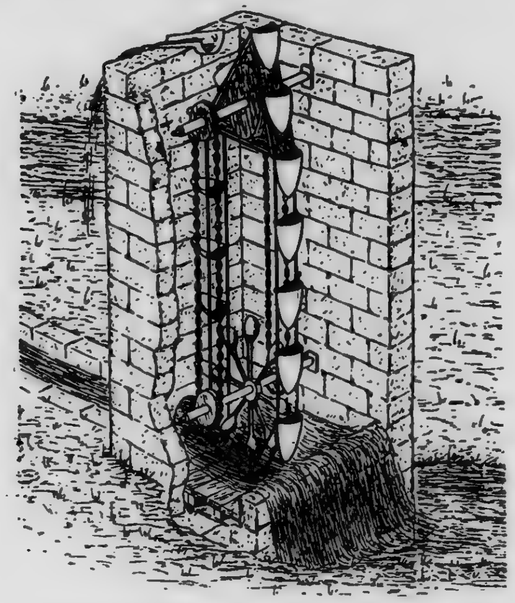

FIG. 9—The waterwheel used for irrigation by Philo of Byzantium, 225 B. C.

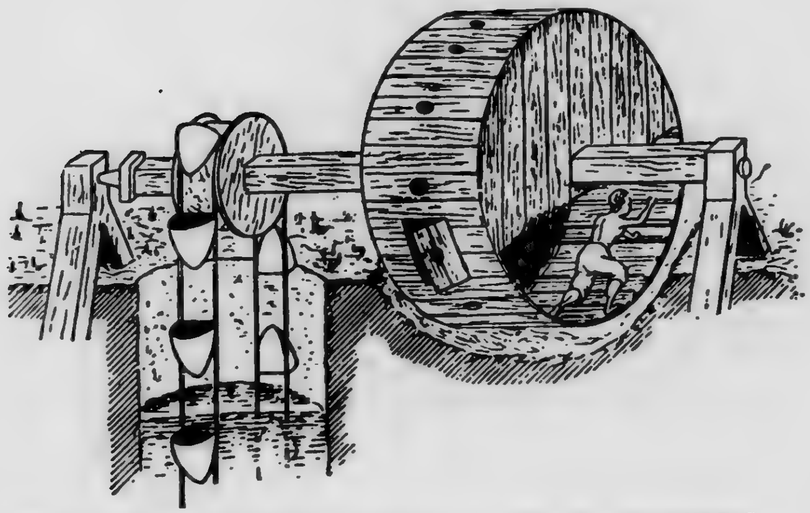

FIG. 10—A treadwheel for irrigation, described by Philo of Byzantium, about 225 B. C.

In another of his machines for raising water, an endless chain of pots was revolved by means of a vertical wheel, which was itself turned by men treading the wide inner rim.

An interesting device of Philo's, was the use of a minature steam blast to blow the fire on the altar.

Whether Philo invented or merely improved upon the waterwheel for raising water is uncertain, but at all events it was widely adopted in various forms in southwestern Asia, where it was employed for irrigation, and turned what had formerly been a heavy manual task to machine labor.

No machines of importance seem to have been as yet used in mining. In Greece the silver mines at Laurion were worked by slaves who were frequently let out by contract. Thus Nicias had thousand slaves whom he let out to Sosias, a Thracian, at a net profit of about three cents a day.

In Egypt under the Ptolemies, the gold mines were worked by criminals. The rock was softened by fire, mined with hammers and picks, and carried out by boys. The ore was pounded with iron pestles and stone mortars, rubbed or ground fine, washed, and then smelted with the aid of lead, salt, tin, and barley bran.

UNDER THE ROMAN EMPIRE

Until about 300 B.C. grain had been pounded with a pestle, or rubbed into meal with saddle stones. This required a tremendous amount of time and work. Among primitive peoples it was usually done by the women of the household, but was later assigned to slaves who might be either women or men.

FIG. 11—The Roman ass and slave mill. About 224 B. C.

About 300 B.C., however, the revolving grindstone was invented, according to Varro, by the Volsinians, whose city in Etruria was captured and destroyed by the Romans in 280 B.C. This first took the form of the quern, which had a conical stone base over which was fitted a concave upper stone which was turned by means of an upright handle at one edge.

The immense importance of the introduction of circular motion, was that it made easily possible the use first of animal power, and later of the water wheel.

Perhaps the first known reference to a mill turned by an ass is in Plautus, one of the greatest Roman comedy writers. He himself labored in a mill, but about 224 B.C. sold enough comedies to enable him to give up the work. In one of these

A pupil of Ctesibius was Philo of Byzantium, who probably lived about 225 B.C. Only a few fragments are extant concerning him, but they credit him with the development of several practical machines of the greatest importance. Philo's sketch for raising water by an undershot water wheel driving by endless chains from wheels at each side an overhead shaft having a three sided sprocket carrying endless link bars with buckets suspended between.

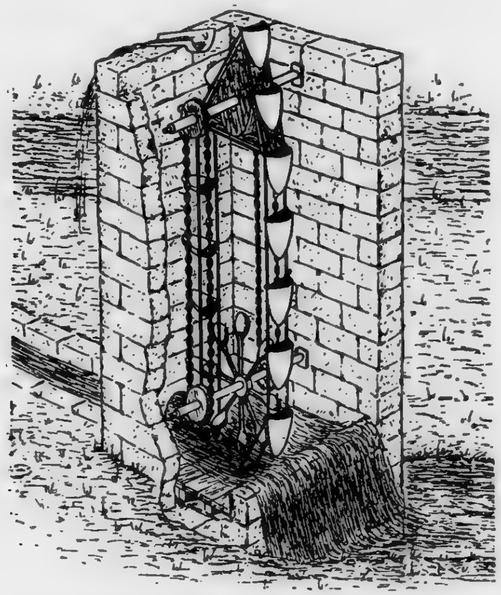

FIG. 9—The waterwheel used for irrigation by Philo of Byzantium, 225 B. C.

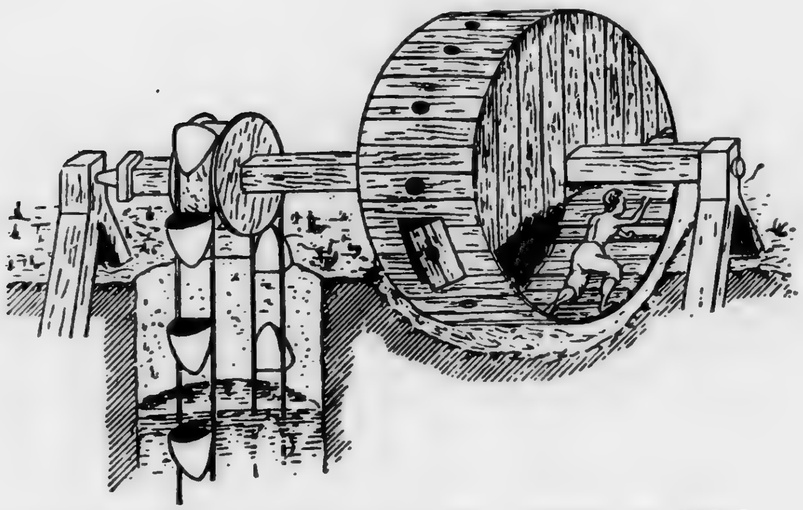

FIG. 10—A treadwheel for irrigation, described by Philo of Byzantium, about 225 B. C.

In another of his machines for raising water, an endless chain of pots was revolved by means of a vertical wheel, which was itself turned by men treading the wide inner rim.

An interesting device of Philo's, was the use of a minature steam blast to blow the fire on the altar.

Whether Philo invented or merely improved upon the waterwheel for raising water is uncertain, but at all events it was widely adopted in various forms in southwestern Asia, where it was employed for irrigation, and turned what had formerly been a heavy manual task to machine labor.

No machines of importance seem to have been as yet used in mining. In Greece the silver mines at Laurion were worked by slaves who were frequently let out by contract. Thus Nicias had thousand slaves whom he let out to Sosias, a Thracian, at a net profit of about three cents a day.

In Egypt under the Ptolemies, the gold mines were worked by criminals. The rock was softened by fire, mined with hammers and picks, and carried out by boys. The ore was pounded with iron pestles and stone mortars, rubbed or ground fine, washed, and then smelted with the aid of lead, salt, tin, and barley bran.

UNDER THE ROMAN EMPIRE

Until about 300 B.C. grain had been pounded with a pestle, or rubbed into meal with saddle stones. This required a tremendous amount of time and work. Among primitive peoples it was usually done by the women of the household, but was later assigned to slaves who might be either women or men.

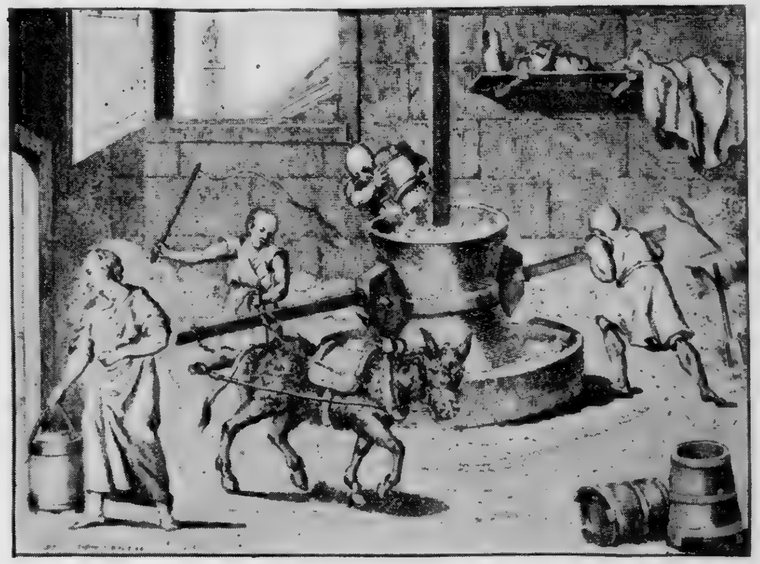

FIG. 11—The Roman ass and slave mill. About 224 B. C.

About 300 B.C., however, the revolving grindstone was invented, according to Varro, by the Volsinians, whose city in Etruria was captured and destroyed by the Romans in 280 B.C. This first took the form of the quern, which had a conical stone base over which was fitted a concave upper stone which was turned by means of an upright handle at one edge.

The immense importance of the introduction of circular motion, was that it made easily possible the use first of animal power, and later of the water wheel.

Perhaps the first known reference to a mill turned by an ass is in Plautus, one of the greatest Roman comedy writers. He himself labored in a mill, but about 224 B.C. sold enough comedies to enable him to give up the work. In one of these

he threatens an ass, that he would give him over to the millers where he would be beaten as he ran around. In such a mill the ass was hitched to a horizontal pole which turned the upper stone as the ass walked around it. We may add that instead of the ass the work was as frequently done by slaves and criminals, and occasionally by poets and philosophers in order to eke out an existence.

Contemporary with the development of the revolving mill, the scientists of Alexandria were discussing various problems of mechanics, and inventing various experimental curiosities, some of which involved important principles. One of these was Hero of Alexandria, who is dated anywhere from the 2nd Century B.C. to the 1st Century A.D. He was a follower of Ctesibius and Philo, and described a number of their inventions as well as his own.

Among mechanical devices he described cogged wheels, pinions and racks, windlasses, various pulleys for raising weights, a vertical endless screw and a wheel with oblique cogs, derricks, capstans, and presses worked by wheels and axles and by screws.

Scientifically, the most interesting of his devices are those involving the use of compressed air, hot air, and steam. He describes siphons, syringes, and the forcing pump used as a fire engine.

In order to make the temple doors open when fire was built on the altar, he made the heat expand the air in a globe, forcing part of the water into another vessel, the weight of which, acting through chains, turned the pivots upon which the doors rested, and opened them.

He used steam to support a ball, and to blow a fire.

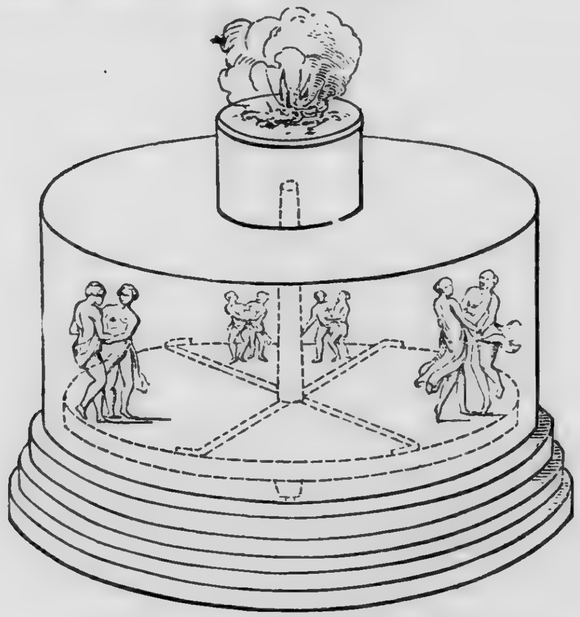

FIG. 12—Steam used to revolve a turntable, by Hero of Alexandria, about 100 B. C.

In a far more important invention, the steam from a covered cauldron entered a ball, and passed out through bent rods, thus turning the ball as in an internal turbine. In a similar way, the hot air from the fire on the altar was made to pass through bent tubes at the circumference of a turntable, which was thus made to revolve and cause figures to dance on top of it.

In another remarkable invention he describes a windmill which acts through a cam to raise a piston and blow an organ. It is a sad commentary, that, after the wind-mill was thus invented and experimentally applied, it was some 600 years before it was reinvented and put to practical use.

The first known notices of the application of the water wheel to turning mills for grinding grain, is probably the epigram of Antipater of Thessalonica, which was written perhaps as early as 85 B.C. This is a remarkable instance of a poet grasping the influence of a new invention. It runs as follows; "Ye maids who labor at the mills, cease your toil. Sleep and let the birds sing alone to welcome the dawn. Ceres commands the water nymphs to do your task. These throw themselves upon the wheel, forcing around the axle, and turn the heavy mill."

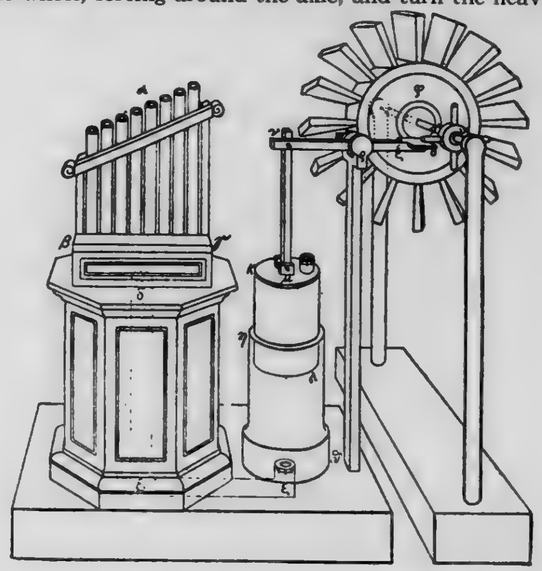

FIG. 13—A windwheel used to drive an organ, by Hero of Alexandria, about 100 B. C.

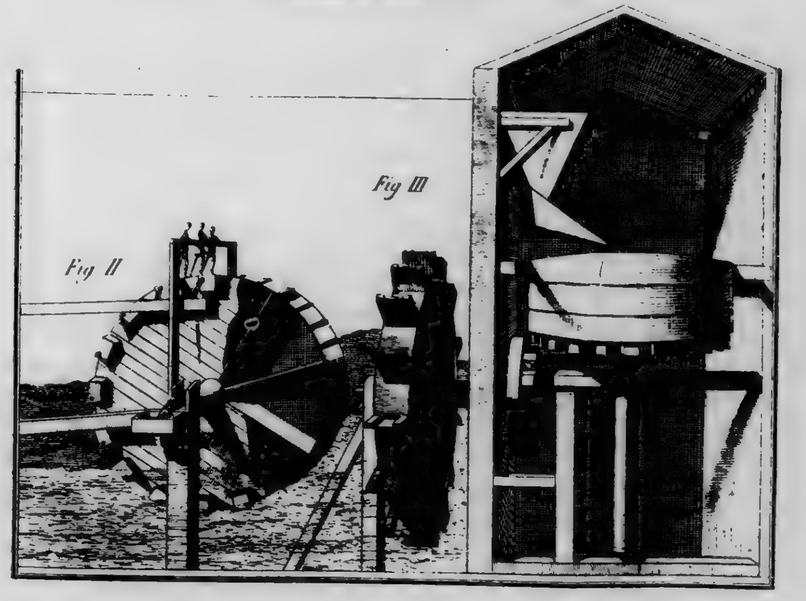

FIG. 14—Roman treadwheel and waterwheel described by Vitruvius about 15 B. C.

After the defeat of Mithridates, the Romans, about 65 B.C., found a water mill in operation near his castle in Capria.

The first water mills in Rome were introduced just before the reign of Augustus, and were so small that they were set up on the open aqueducts which brought water into the city.

Vitruvius, the Roman architect, who wrote about 15 B.C., described wheels for raising water and for grinding grain. On the end of the axle was a verticle drum with teeth, and connected with this a smaller horizontal one which turned the mill stone.

In mining, according to Diodorus, who wrote in the 1st Century B.C., the Romans used the Archimedean screw to remove the water, also cutting trenches deep under ground to divert the stream.

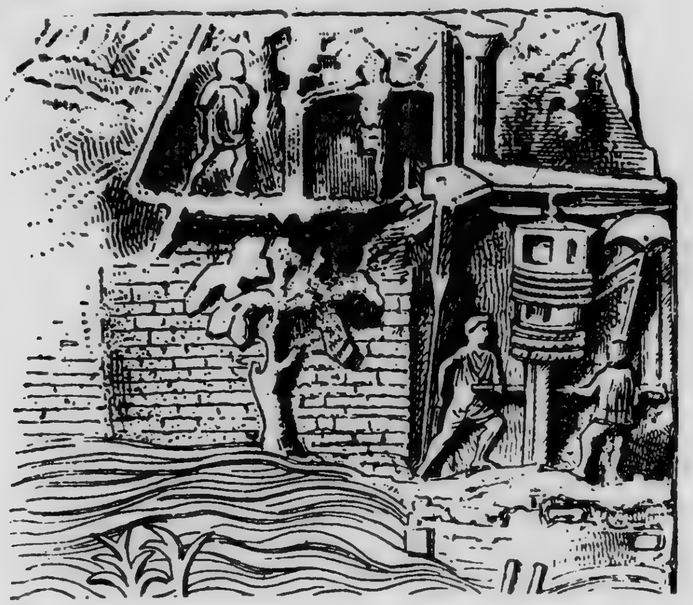

FIG. 15—A Roman machine for breaking rock underground. 1st century A. D.

Pliny, in the 1st Century A.D., gave a vivid account of the great operations in mining and smelting then carried on in Spain. The rock was crushed by hinged bruising machines having pieces of iron weighing 150 pounds each. These seem to have been hung on stakes by means of ropes, and to have been swung like rams up against the rock. The ore was passed out by long lines of men each handing pieces to his neighbor. Remains of the time indicate that wheels with cups on the circumference were used to raise the water from one level to another.

For washing the ore, streams were conducted from still more elevated heights, in many cases at a distance of more than a hundred miles. Aqueducts had to cross over valleys, or rocks hewn away to make room for troughs. Sometimes the workman had to be suspended by ropes and pulleys in order to cut out a bed for the stream.

Although the Romans in their engineering and building operations employed various arrangements of derricks and capstans and pulleys, the tread wheel crane seems to have been the favorite machine for important work.

A bas-relief found at Capua, illustrates two workmen treading a verticle wheel, from which ropes extend through a pipe to a floor below.

A still more remarkable bas-relief in the Lateran Museum, depicts a great Roman polyplaston or multiple-pulley crane. Here five workmen may be seen

inside the wheel; while two at the top of the crane and two below are arranging the ropes. About eight pulleys are represented on the crane, and each pulley seems to carry at least two ropes.

In the 2nd Century A.D., Apuleius gives a vivid description of the interior of a mill and bakery where broken down asses and horses turned the mills, and worn out slaves made the flour into bread.

The whole Greek and Roman civilization, it must be remembered, rested on slavery. Athens had 400,000 slave to 100,000 free citizens, and slaves fairly swarmed over one another in the great households in Rome. It was not until the

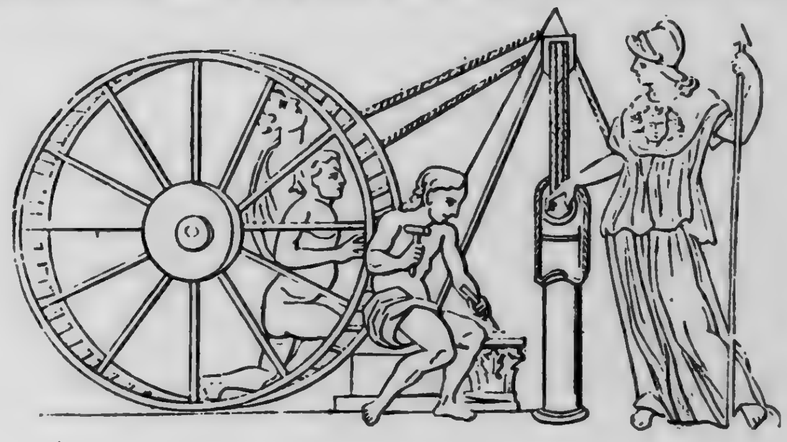

FIG. 16—A Roman treadwheel for elevating.

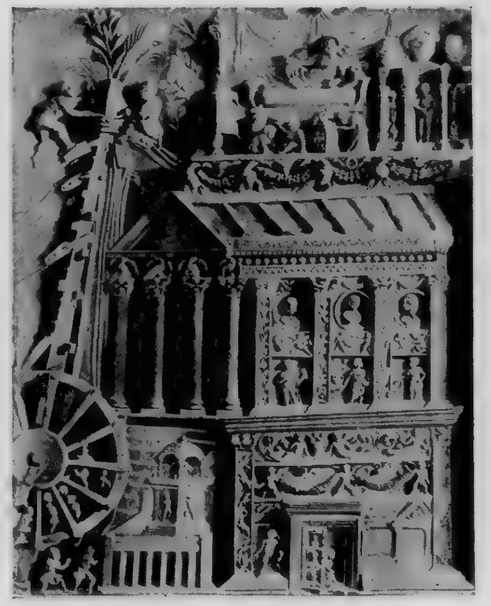

FIG. 17—A great Roman polyplaston or multiple pulley. Empire period. 1st century.

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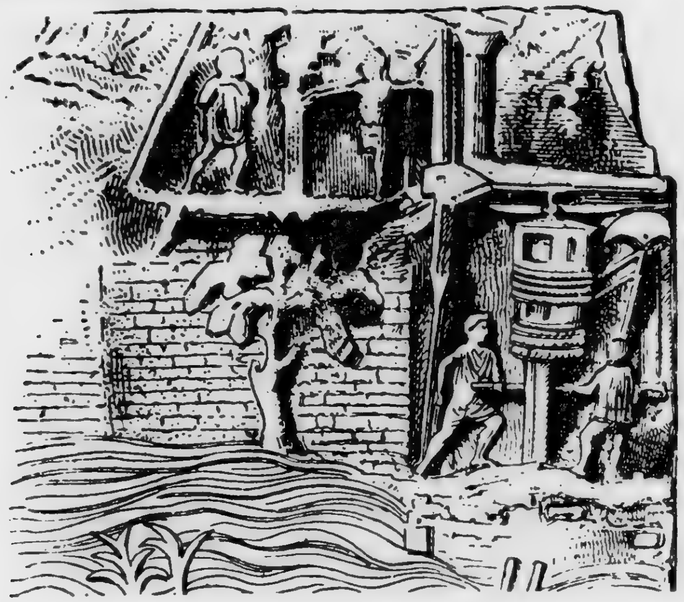

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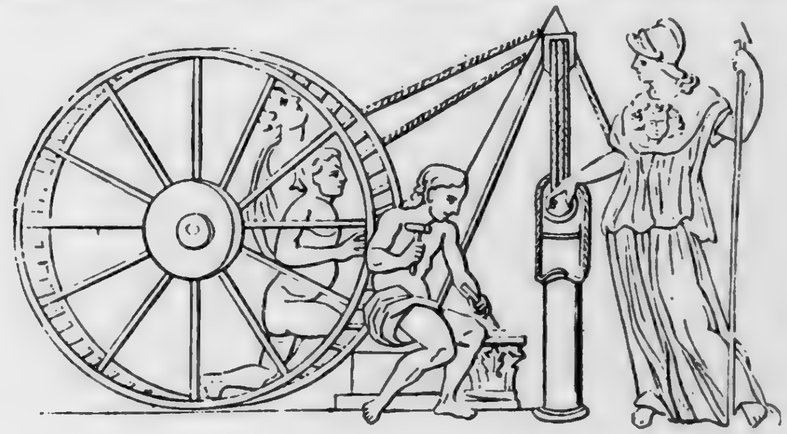

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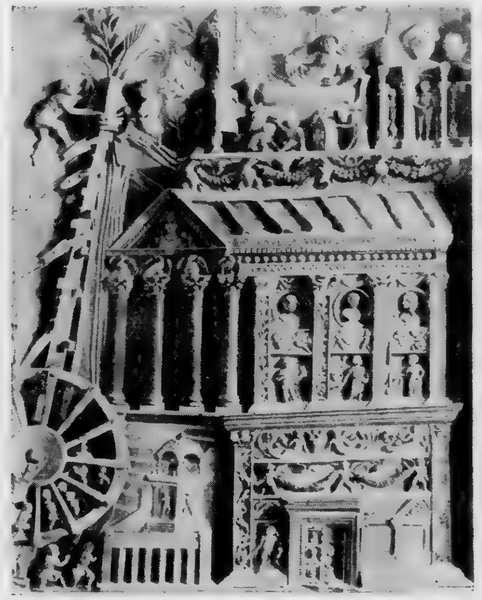


FIG. 17—A great Roman polyplaston or multiple pulley. Empire period. 1st century.

later Empire that water power became sufficiently developed to compete on equal terms with slave labor, but the water mills, as they became more efficient and slaves more expensive, gradually displaced slave labor in the bakeries, in irrigation work, and in the sawing of marble.

In a poem of Ausonius is a reference to a water mill employed for cutting stone, which was done by means of toothless saws and sand. This, of course, implies a change from circular to reciprocal action, but the method thus employed is unknown.

At the end of the 4th Century we find water mills on the Janiculum hill at Rome dependent upon to supply the city with grain instead of animal or slave mills.

IN THE MIDDLE AGES

When the barbarians swept over the Roman Empire, the roads and aqueducts were partly destroyed, and the deep mines no longer worked. The lines of interconnection were cut, and commerce ceased. The theoretical knowledge of antiquity was largely lost, and only the practical matters of everyday use retained.

Among the machines preserved was the watermill, and Procopius gives an interesting account of how Belisarius, when besieged by the Goths in 536 A.D., fed Rome by inventing floating mills which he placed on the Tiber.

About the middle of the 6th Century the first elevator on record for passengers and freight was used in the convent of St. Catharine on Mount Sinai.

The Mohammedans, who began their conquest in 622 A.D., overran Egypt in 636 A.D. Alexandria was taken after a siege of fourteen months, and its great library destroyed. This still further cut off the knowledge of the past from the Dark Ages.

From Arabian sources comes the first legend of a wind-mill applied to grinding grain. Firouz, the assassin of the Caliph Omar in 644 A.D., claimed to be able to construct one, but, instead of doing so, stabbed the Caliph.

In the meantime another important use for a mill to do heavy work had been developed. The sugar-cane was introduced into Persia from India about 500 A.D., and when the Arabs overthrew the Persian kingdom in 640 A.D., the cane was being crushed with stone rollers driven by water wheels.

Another employment for the water wheel was in making pulp for paper. The capture in war of some Chinese craftsmen by the Mohammedans, introduced paper manufacture into Persia about 750 A.D., and not long afterwards mills were applied to pounding up the pulp.

A new power was being developed in the form of fiercely burning or semiexplosive material. About 678 A.D. Kallinikos, who had fled from Heliopolis to Constantinople, made a liquid fire to be discharged from siphons, by which hundreds of the ships of the Saracens were destroyed at the Battle of Kuzikos, and the Siege of Constantinople raised. This was the famous Greek fire which protected Constantinople for centuries. Anna Comnena, daughter of the Emperor Alexis, wrote that in 1103 A.D. it was discharged through flexible apparatus, which may imply leather hose. A picture of that date depicts a sort of syringe being used for the purpose.

Theophilus, the monk, wrote of the various arts between 1050 and 1100 A.D., but about the only new operation he mentions is the forming of wire by drawing it through a plate instead of hammering it out, but the work was still done by hand.

Theophilus also describes a mill in which the pestle stood erect in the mortar, and was turned around by hand or animal power.

The Domesday Book, about 1086 A.D., complained that there was a tide-mill in the entrance of the port of Dover which interfered greatly with ships.

Early in the 12th Century we begin to get notices of wind-mills in the West, and they soon became common, although the privilege of running them was reserved mostly for nobles or monasteries.

A grotesque drawing of a water-mill of that century shows a small vertical lantern on the axis of the lower millstone. The lantern seems to have been an invention of the Middle Ages, and, at all events, is characteristic of the gearing of the period.

In the 13th Century foot-power had come into use for running the lathe, for a stained glass window in the Cathedral of Chartres shows a workman turning a lathe in this way.

FIG. 18—A lathe worked by foot power, 13th century, from a painting at Chartres.

About 1250 Villard de Honnecourt depicted a saw-mill in which the saw was lowered by four cams on the shaft of a water wheel, and raised again by a spring pole. One end of the saw was fastened to the pole, and the other to a frame of five pieces of wood which had a crude link action. He also depicts a saw for cutting piles under water, and a large mechanical sling which was worked by a heavy weight on one end, the lighter end being pulled down by capstans and pulleys before being released.

In 1232 Chinese used rockets to carry fire into a fortress, and the same device was described by Marcus Graccus in 1250. At the same date Roger Bacon de-

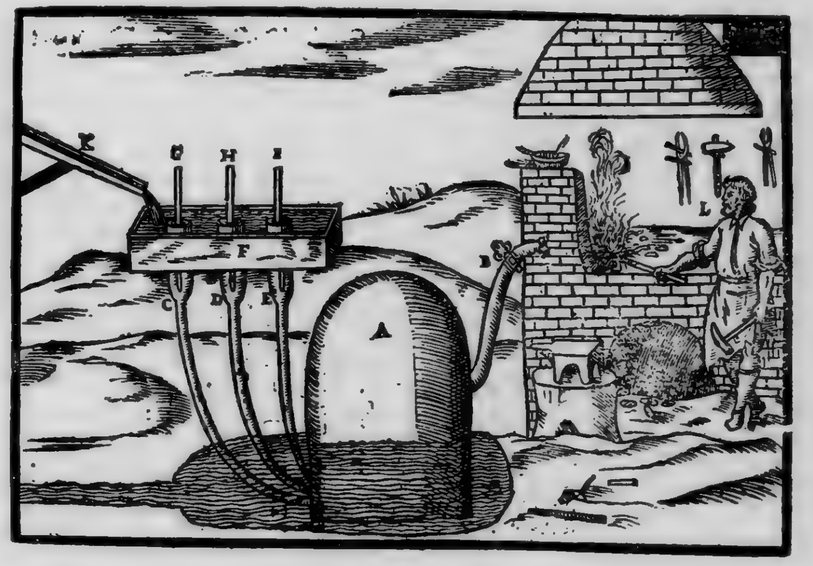


FIG. 19—Branca's designer of compressed air to blow a bellows. After the Catalan forge.

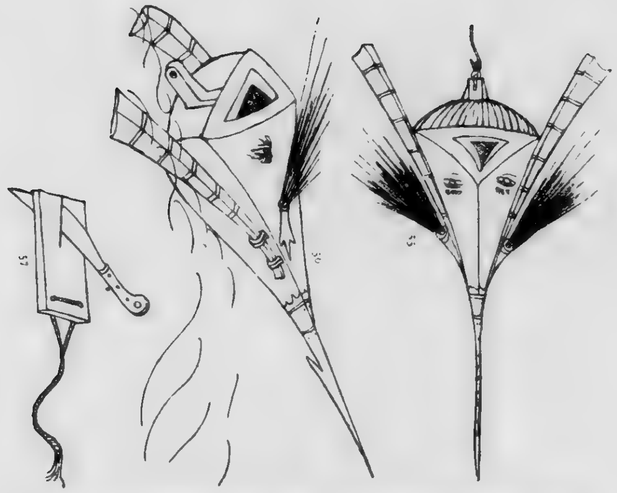


FIG. 20—Rockets used to drive torpedos against ships, 1420.

FIG. 21—An endless belt conveyor, about 1430.

scribed gun powder, and in 1313 Berthold Schwarz by reversing the action in the rocket invented the gun.

By that time industry throughout western Europe was mostly organized on the guild system, which required an apprenticeship of about seven years, and three years as a journeyman, before a man became a master workman. All the members of a trade in a city were combined in a guild, the officers of which saw that supplies were equably distributed, the *grade of workmanship maintained*, and prices approximately the same for *similar work*.

In 1306 Rudolph of Nuernberg made a great improvement in wire drawing. He kept this as secret as he could, but finally the other guild members wormed the secret out of his son. What it was is unknown, but it probably consisted in applying a wheel, or perhaps even a water wheel to the purpose. At all events, it was so important to the industry, that he was long credited with being the inventor of wire drawing itself.

Sometime during the early Middle Ages the Catalan forge was invented for supplying a blast for smelting. It was said to have originated at Catalonia, Spain, where there were numberless small mountain streams. The water was caught in a small reservoir above the furnace, and, after the furnace was lighted, was permitted to run down a pipe back of the furnace. The stream sucked the air down with it, and this escaping through holes in the pipe below the furnace, acted as a constant blast. This principle is said (unconfirmed) to be in use today in this country.

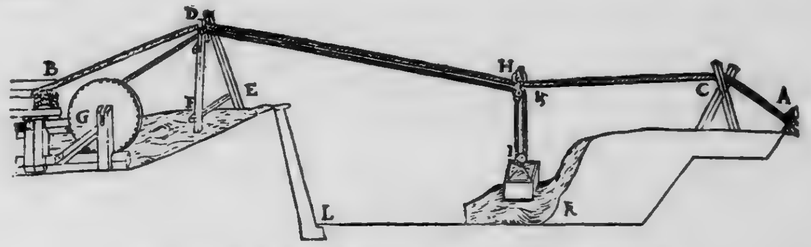


FIG. 22—Design for a rope conveyor, 1438. "G" is a treadwheel.

A miniature of 1338 shows a blacksmith's forge with a canopy top, and bellows peing worked by what seems to be a compound lever.

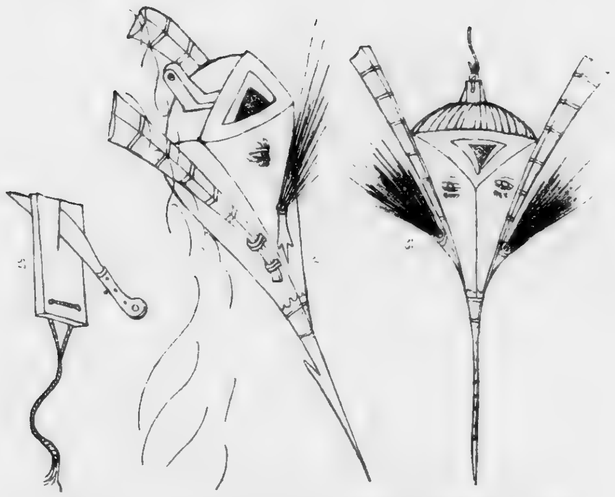
Several military manuscripts, written about 1400, give a vivid idea of the mechanical inventions then in use for war. In Conrad Kyeser's Bellifortis, written between 1395 and 1405, some of the most novel machines include an elevator raised by a balanced pole together with rope pulleys; a tower raised by a screw, a siphon across a valley and over a hill, wheels with holes on the side for raising water, pulleys and windlasses for drawing great bows, guns arranged like the chamber of a revolver, the use of powder for blasting, and boats with paddle wheels.

FIG. 23—Water wheels for blowing bellows, early 15th century.

Fontana, the Italian, about 1420 pictured rockets being used to drive torpedoes against the side of ships.

In a manuscript of about 1430, we find a wheel and cams used to run a stamp mill for powder, boring by means of a wheel, and a pile driver worked by many men with the aid of a pulley.

A highly interesting miniature of this date depicts supplies being sent across a ravine to a castle by means of an endless rope running over a wall at each side of the ravine. This is perhaps the earliest illustration of a belt, though it was not yet used to transmit power.



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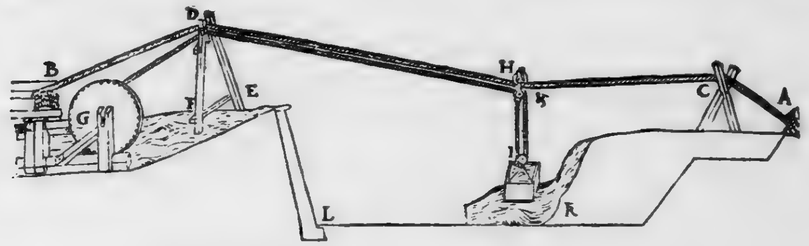

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Marianus, about 1438, depicted an endless chain on a wheel together with a screw and cogs for the same purpose. He shows a water wheel used to blow a bellows, and a vertical tread-wheel employed to raise weights. In one drawing a cannon is suspended by a pulley hanging from a rope which is stretched across a stream, and is being transported by this means.

An interesting series of pictures engraved on a silver vase at Gand, France, early in the 15th Century, depicts the water wheel being applied to blowing the furnace in smelting. In one scene men are carrying out a bucket of ore on poles,

FIG. 24—Car on a track, perhaps rails, early 10th century.

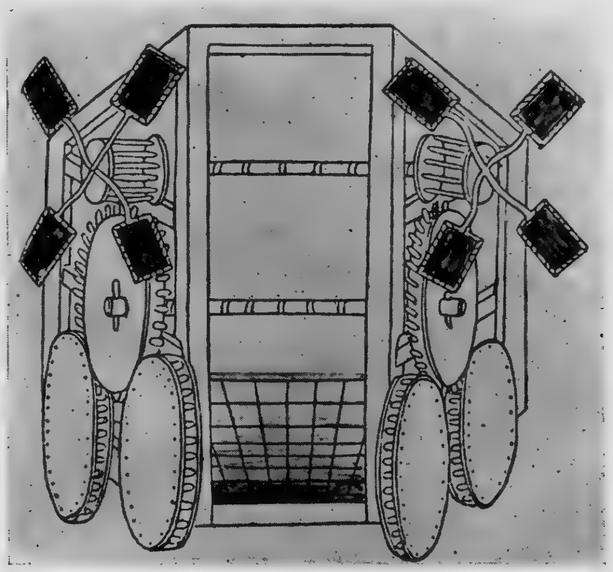

FIG. 25—An attempt to use windwheels for land transportation, 1472.

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A house book of about 1475 pictures a rude lathe, though the method of driving it is not indicated.

LEONARDO DA VINCI

For the progress during the 14th and 15th Century we refer to the sketches of Leonardo da Vinci who was not only one of the worlds greatest artists but the greatest engineer and inventor of this period. He left a number of sketches of mechanical devices which show the development of mechanics then in use for war and building of forts and temples.

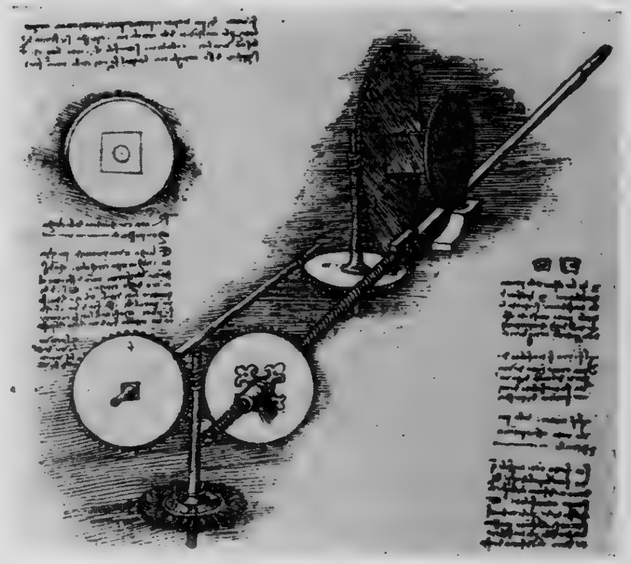

FIG. 26—A water turbine by Leonardo da Vinci, about 1500. Designed to roll rods for cannon.

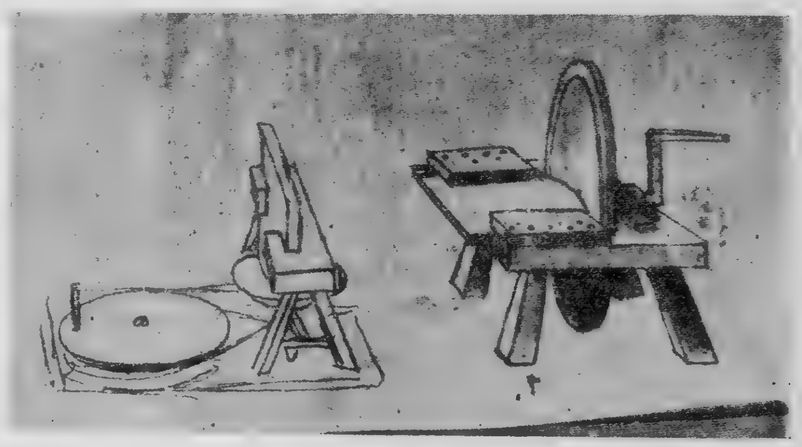

FIG. 27—Grinding Machines Designed by Leonardo da Vinci, 1500

Among his many designs the following are most closely connected with power. Two of horizontal water wheels,—one to roll, and one to draw the iron rods which were fastened together like barrel staves to form one type of cannon of the period.

Marianus, about 1438, depicted an endless chain on a wheel together with a screw and cogs for the same purpose. He shows a water wheel used to blow a bellows, and a vertical tread-wheel employed to raise weights. In one drawing a cannon is suspended by a pulley hanging from a rope which is stretched across a stream, and is being transported by this means.

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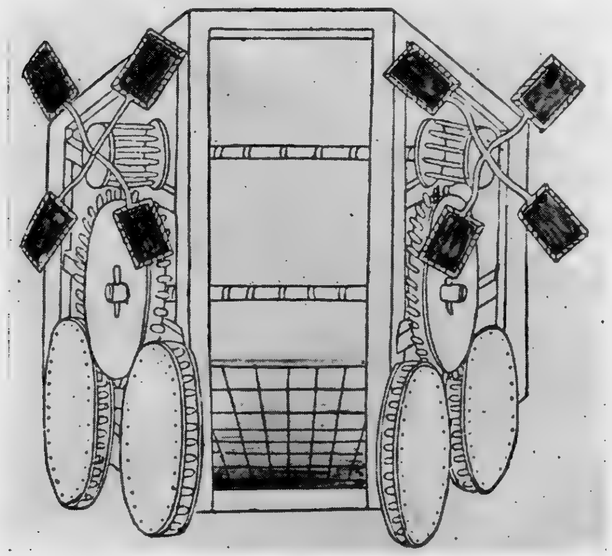

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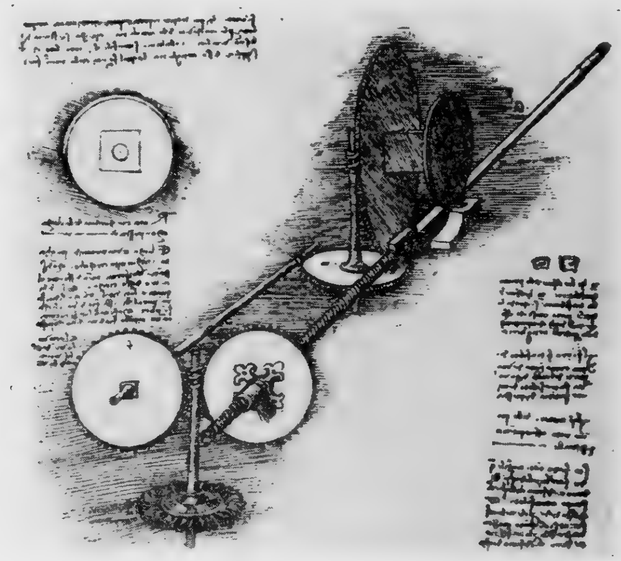

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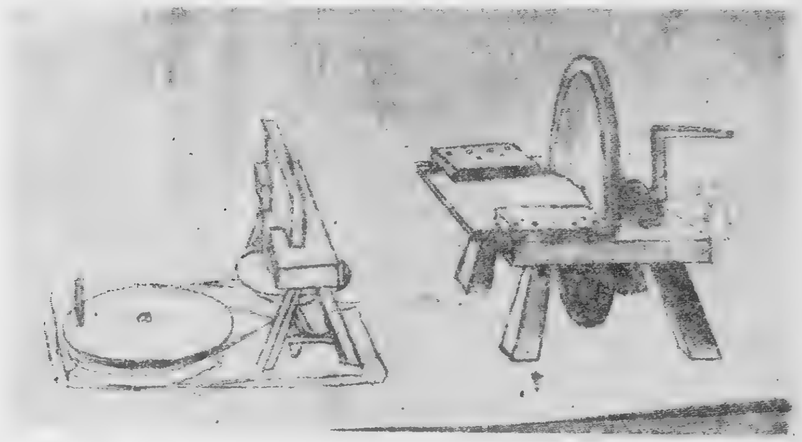

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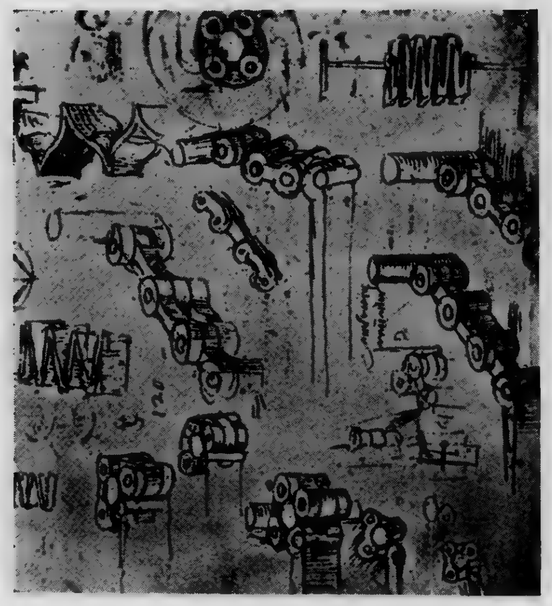


FIG. 28—Codice Atlantico 1484.
Sprocket chains for power transmission
Leonardo de Vinci 1452-1519.

Detailed drawings of swinging cranes, in which the power is furnished by vertical tread wheels. These or similar cranes were no doubt used in construction of canals, moats, and fortresses.

A gun in which steam was to be used instead of powder, A head blowing steam which may have been intended to drive a turbine, as in the later sketch by Branca.

Derricks used in a cannon foundry, horizontal boring machines, and earth drills.

A file cutter which was run by a weight. A similar idea was employed in mills soon afterwards.

Wheels with various sorts of teeth or cogs, including bevel gears and screw and gear, pinion wheels in a road measure, also in a boat with a paddle wheel.

One of his most interesting sketches is of a number of linked chains. These illustrate the advancement in forging to meet the demand for power transmitting units and that the craftsmen and engineers then recognized the need and were developing and utilizing link and roller chains.

Other sketches by Leonardo da Vinci furnish records of molds for concrete, revolving and breech cannon, cannon molding, a saw run by a tread wheel, a polishing wheel driven by a belt, and a wheel for rope making.

IN THE 16TH CENTURY

In the 16th Century we leave the age of manuscript sources for that of printed books, and meet with a number of military, engineering and mining volumes.

The Pirotechnia of Biringucci, published in 1540, shows the water wheel being practically applied to drawing wire and iron rods, to boring cannon, and blowing bellows. He pictures the grinding of ore in the amalgamation process, the liquating furnace, and various other processes in smelting.

At the time a mill at Nurenberg seems to have been successfully using water power in both rolling and cutting iron.

It may be worth noting that the first definite account of a universal joint is that of Cardanus, in 1545, who fitted one to the compass.

Olaus Magnus, archbishop of Upsala, in his latin History of Northern Peoples gives a curious picture of a vertical tread wheel employed for hoisting in a mine, and another of little water wheels being used to work trip hammers and to blow a furnace.

The next year, or in 1556, Agricola's posthumous work De Re Metallica was published. This gives a detailed description of German mining at the time.

Among the many interesting illustrations, several of the most novel show mines being ventilated by means of wind wheels, and also by means of bellows worked by tread-mills.

There are two cuts of cranes with trolleys running back and forth on the arms.

Stamp mills, grinding mills, bellows, and trip hammers are driven by water wheels; while vertical tread-wheels, inclined tread-mills, and various other sources of power are employed.

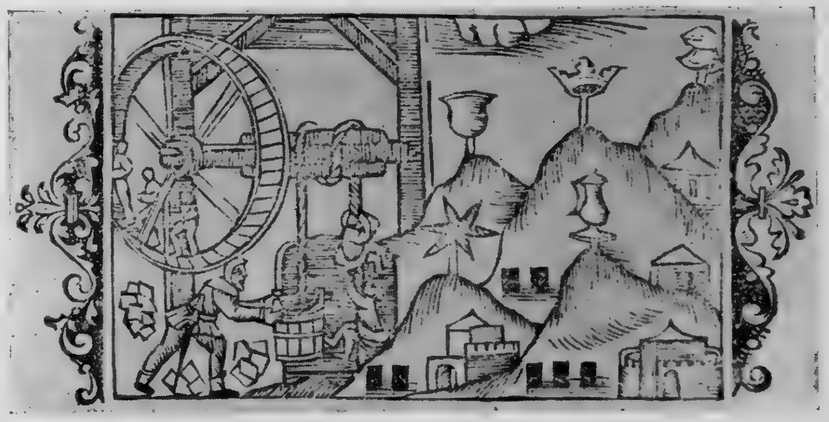
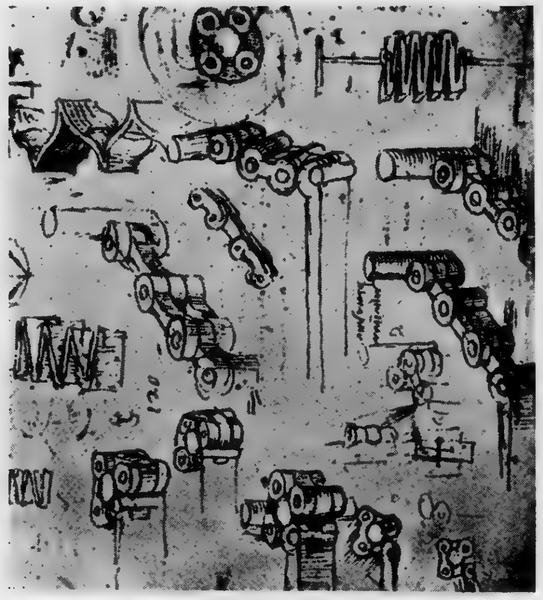


FIG. 30—A tread wheel used in mining in Sweden, 1555.



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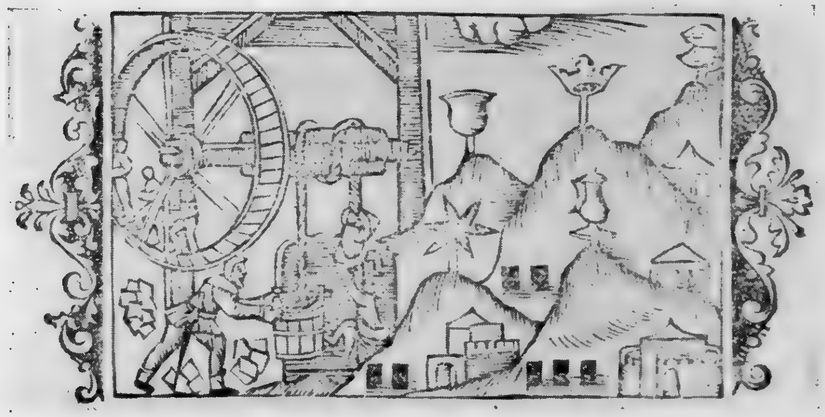

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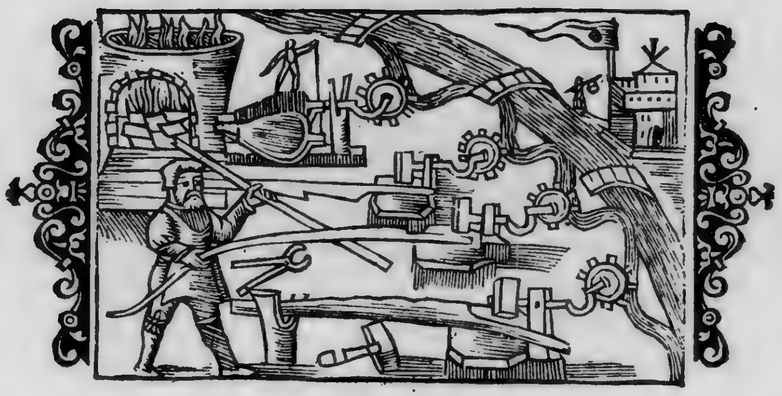

FIG. 31—Triphammer and bellows worked by water power, Sweden, 1555.

A woodcut by Amman in 1568 (the 1st picture of a belt) shows a hollow ware worker turning his wares with a lathe. The lathe was driven by a large wheel which was turned by hand and connected with the lathe by means of a belt, though this only partly appears in the picture. Besson in 1578 represents a chain belt in use to drive a mill.

Besson gives several representations of lathes, two of which are driven by a treadle, by means of a rope which passes around the lathe and upwards to a bow in the ceiling. The other is turned by a treadle and a weight. He has a curious engraving of a bucket elevator in which the buckets are fastened to an endless chain. This goes around a ladder, and is supposed to be worked by an endless screw and windlass which is turned by hand at the top.

FIG. 32Windwheels and fans for ventilating a mine, from Agricola, 1556.

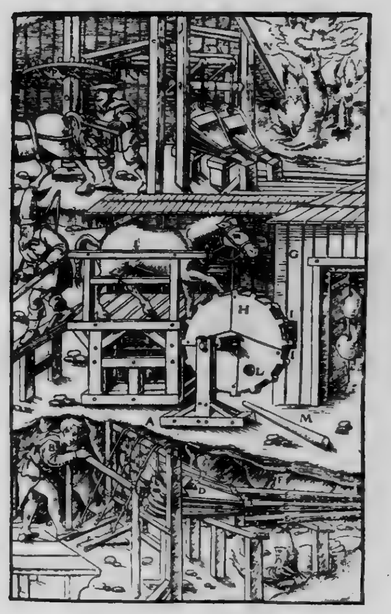

FIG. 33—Bellows for ventilating a mine Agricola, 1556.

FIG. 34—Forging by waterpower, Agricola, 1556.

FIG. 35—A wheel and belt used in turning. 1568.

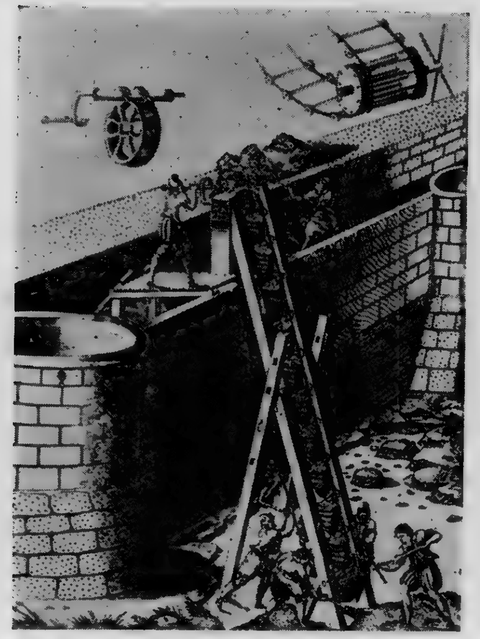

FIG. 36—Plan for an elevator, 1572, by Besson.

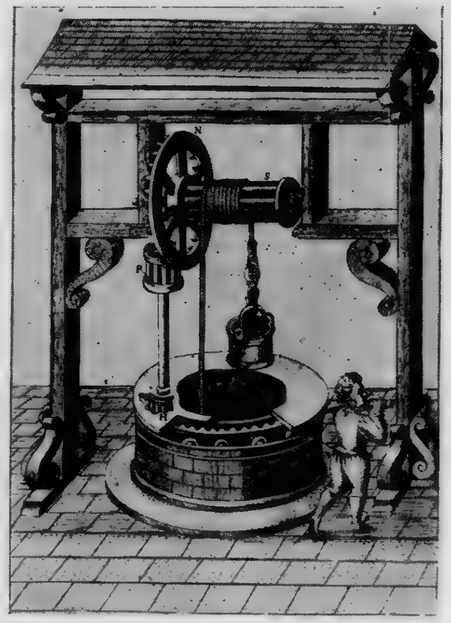

FIG. 37—Roller bearings depicted by Ramelli, 1588.

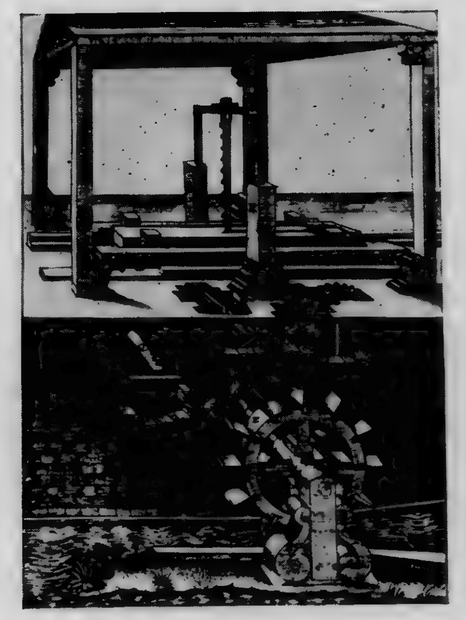

FIG. 38—Waterpower applied to sawing, with automatic advancement of the work, 1588.

FIG. 39—Link belts used in elevating. Ramelli, 1588.

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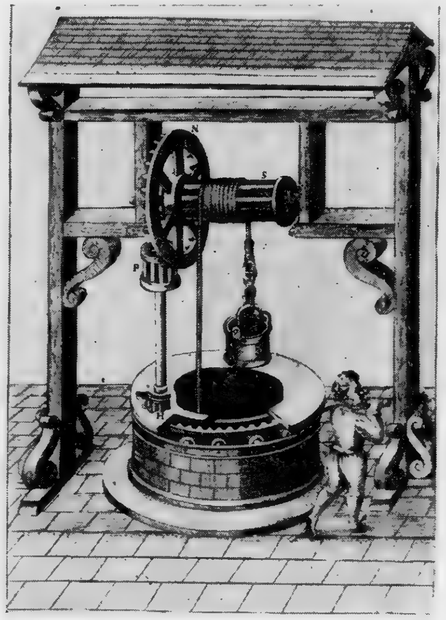

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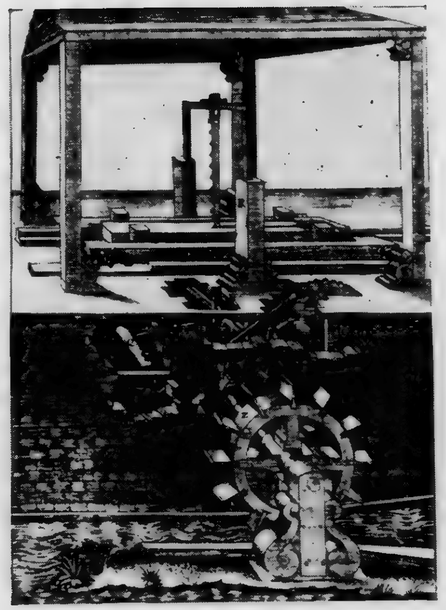

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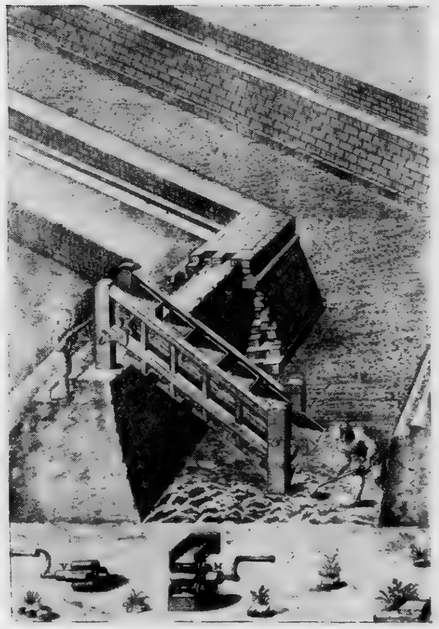

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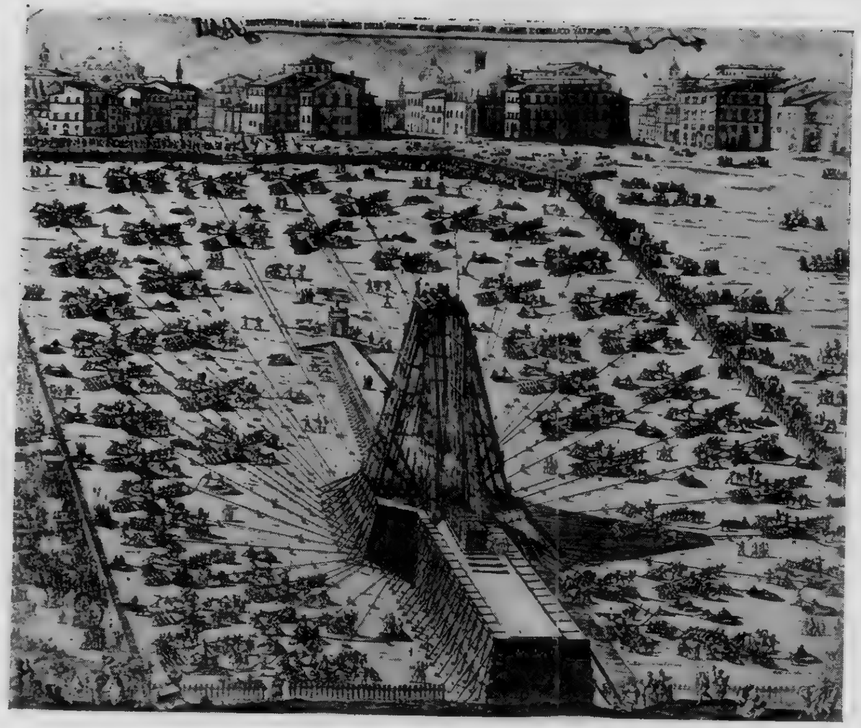

FIG. 40—Raising the obelisk of St. Peters, 1586.

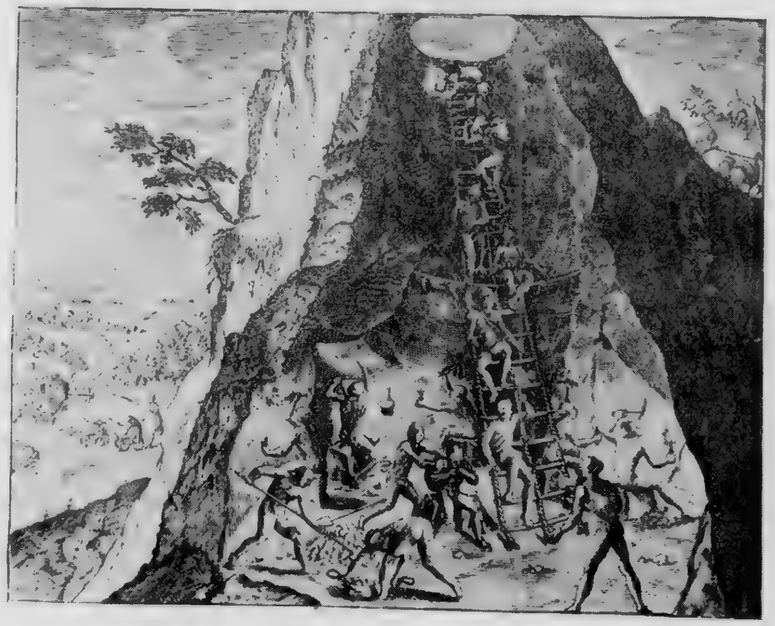

FIG. 41—Mining in Peru by rope ladders, 1590.

Ramelli, in 1588, besides depicting all sorts of cog wheels, has a remarkable illustration of roller bearings around the top of a well on which ran an horizontal wheel which was turned to drive a shaft and raise the water.

Another important engraving by Ramelli depicts linked chains raising buckets of dirt up an inclined frame from a moat to the top of a fortification. Here, as in the illustration by Besson, the only power depicted was manual labor.

In 1586, the raising of the obelisk of St. Peter's of Rome required an inclined plane, 46 capstans, 140 horses, and about 600 men with numberless ropes and pulleys. It was about 83 feet high, and was estimated to weigh nearly 500 tons.

In the silver mines of Peru at the end of the 16th Century, the miners carried the ore on their shoulders, up rope ladders, a from depth of about 150 fathoms. Wind-mills, however, were employed at Potosi for stamping and amalgamation.

FIG. 42—Windmills used in smelting at Potosi, 1600.

Wire rope had already become common. It was mentioned by Leonardo da Vinci, and one of the ships of the Spanish Armada which was sunk in 1588 had on it a large quantity of copper wire rope which was discovered by divers in 1912.

IN THE 17TH CENTURY

In the 17th Century the extension of the use of water power began to make possible larger factories which were located in districts independent of the guilds, and from this time the guilds gradually declined.

At the beginning of the century Stradanus illustrated a polishing room of an armorer's plant in which a number of grind-stones were turned by one shaft; while in 1607 Zonca depicted a similar room where not only the shaft, but a rope belt was employed to transmit the power from water wheels to the stones.

In 1601 Porta described how water heated in a small boiler would produce hot air or steam which could be carried through a tube and used to force the water from a second enclosed vessel out of the mouth of the fountain.

The first to distinguish clearly between air and steam seems to have been van Helmont in 1610.

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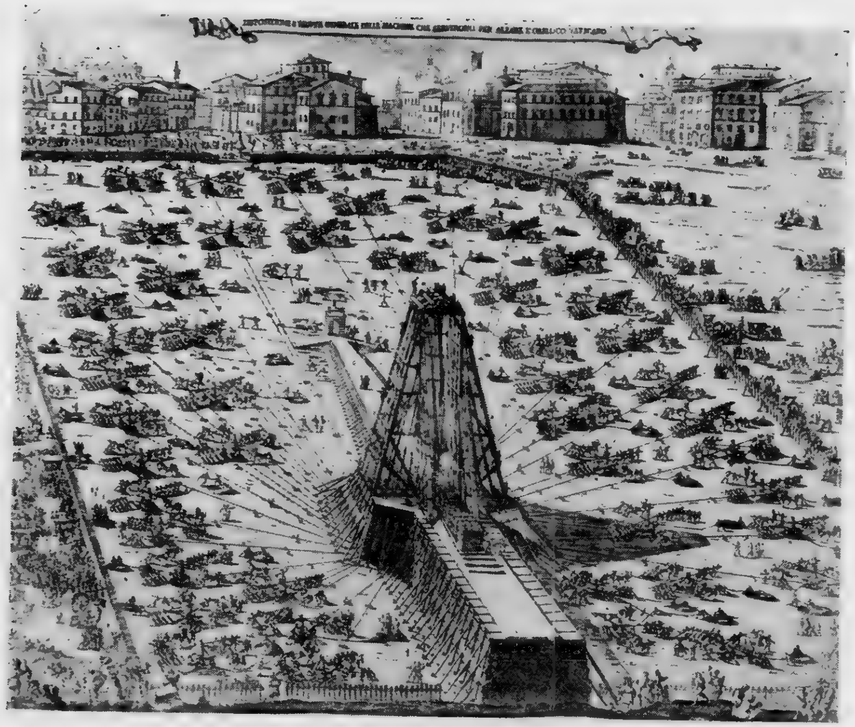

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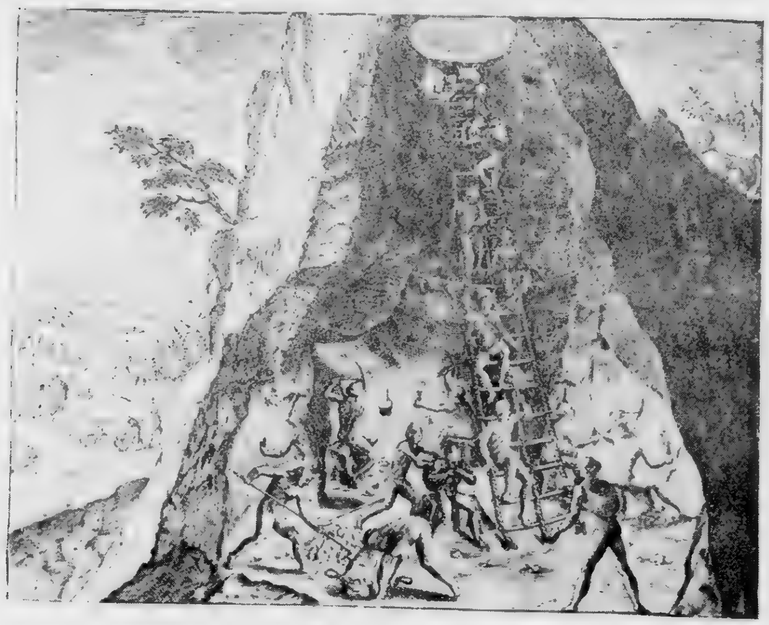

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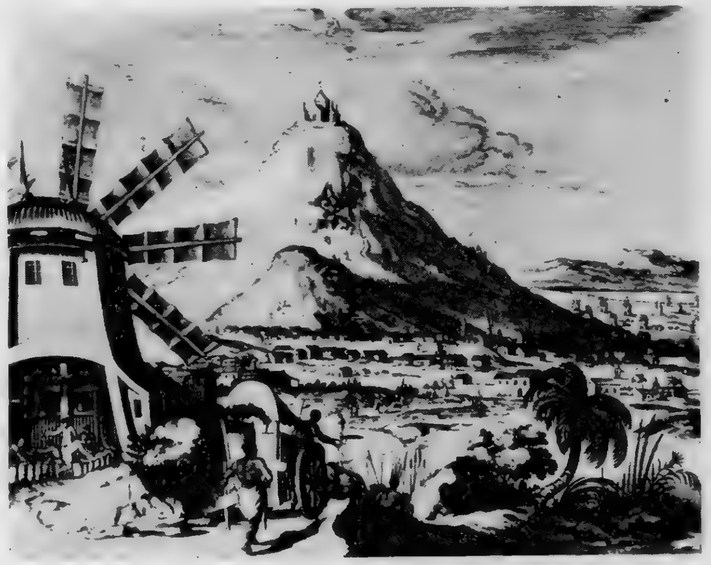

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FIG. 43—A large polishing plant for armor, 1600.

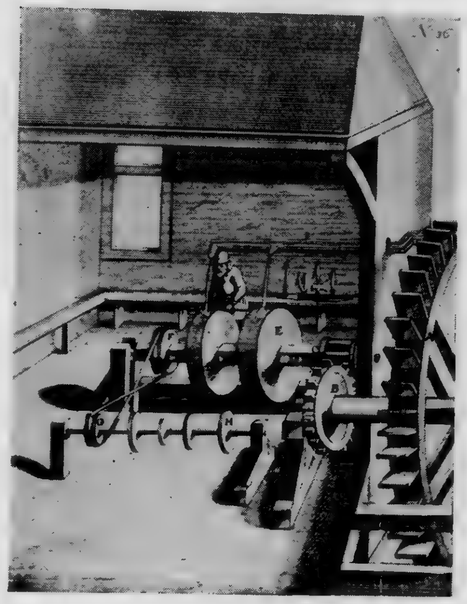

FIG. 44—Zonca's painting. Shafts and a belt from water wheel, 1607.

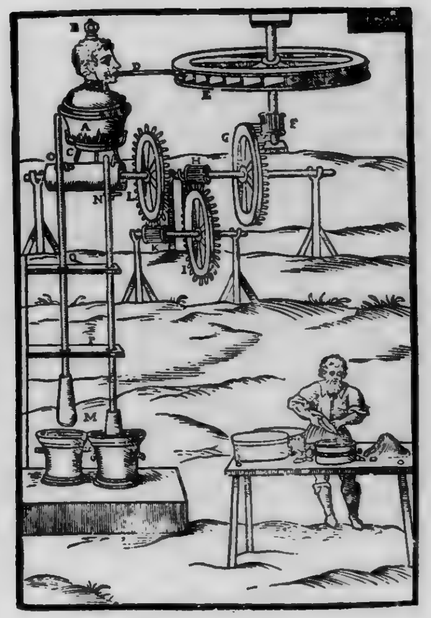

FIG. 45—Branca's cut for a steam turbine 1629.

FIG. 46—Branca's design for a hot air turbine, driving rolling mill, 1629.

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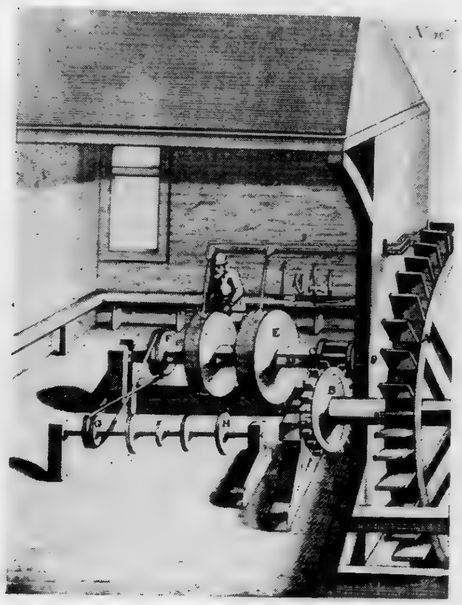

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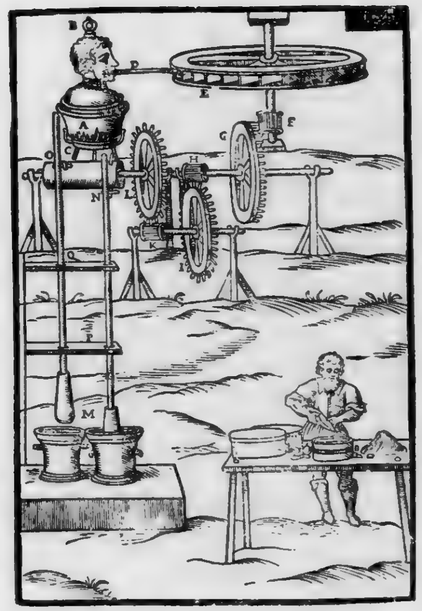

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FIG. 46—Branca's design for a hot air turbine, driving rolling mill, 1629.

One of the most original, if not the most practical, of the engineers of that period was Branca, who published at Rome a little book entitled Le Machine in 1629.

In this he depicts a steam turbine as employed in driving a small stamp mill. Since similar illustrations appear in the works of succeeding philosophers, it is probable that this was demonstrated experimentally, though never applied practically.

He also shows hot air from a fire rising up a tube and turning a small wind wheel, which was used to drive a little rolling-mill. In each case the power was transmitted by toothed wheels and pinions.

An invention of his which was probably put into practical use, was the turning of spindles in silk reeling by means only of friction which was light enough so that

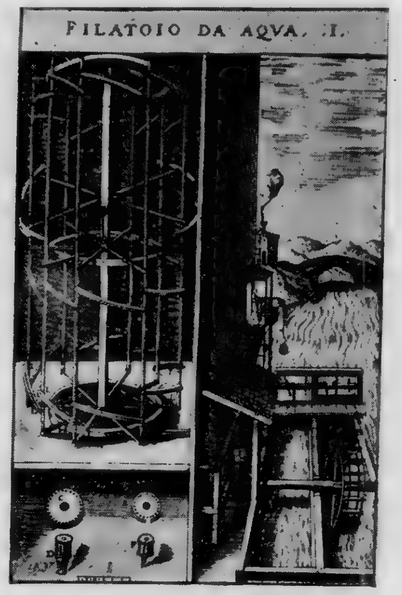


FIG. 47—Waterpower applied to silk reeling with friction transmission. Branca, 1607.

if the thread knotted, the spool would stop and the thread would not be broken. The loom was first set up in France in 1656. and served as a model for all made in France and Holland. Stocking knitters were established in Paris in 1527.

In the second half of the 17th Century the forms of cogs and teeth began to be investigated, though chiefly by mathematicians. Christian Huyghens, who applied the pendulum to the clock, realized that the wheels in it should run as smoothly as possible, and even investigated, in a small way, the evolution of the cycloid, and traced the evolute. Epicycloids were also discussed in a theoretical way in 1674 by Desargues and Olaf Roemer. In 1694 De la Hire recommended the use of this form. But little was done to introduce either the evolute or epicycloid practically for about a century.

Savery's steam engine was invented in 1698, and Newcomen's in 1705. Both were inefficient, but were nevertheless used in a small way to draw water from mines.

IN THE 18TH CENTURY

Economic conditions in the first half of the 18th Century may be epitomized by the fact that the average wages of the skilled workman in England were about $2.40 a week; while wheat varied from $1.00 to $1.50 a bushel. Thus the carpenter or mason could earn only from 2 to 3 bushel of wheat for his week's work.

FIG. 47A—Mining, and a car on rails, 1629.

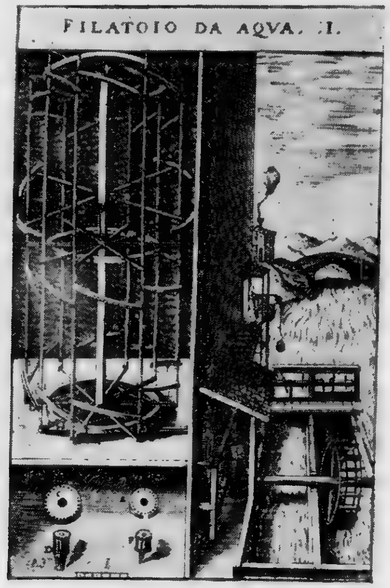
FIG. 47B—Interior of a mine and a car on rails, 1650.

One of the most original, if not the most practical, of the engineers of that period was Branca, who published at Rome a little book entitled Le Machine in 1629.

In this he depicts a steam turbine as employed in driving a small stamp mill. Since similar illustrations appear in the works of succeeding philosophers, it is probable that this was demonstrated experimentally, though never applied practically.

He also shows hot air from a fire rising up a tube and turning a small wind wheel, which was used to drive a little rolling-mill. In each case the power was transmitted by toothed wheels and pinions.

An invention of his which was probably put into practical use, was the turning of spindles in silk reeling by means only of friction which was light enough so that



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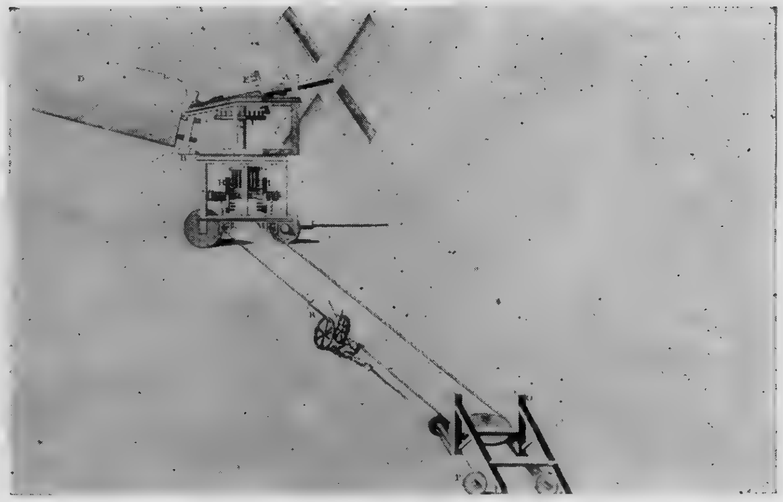


FIG. 48—A project for a windmill to plow a field by rope transmission, 1720.

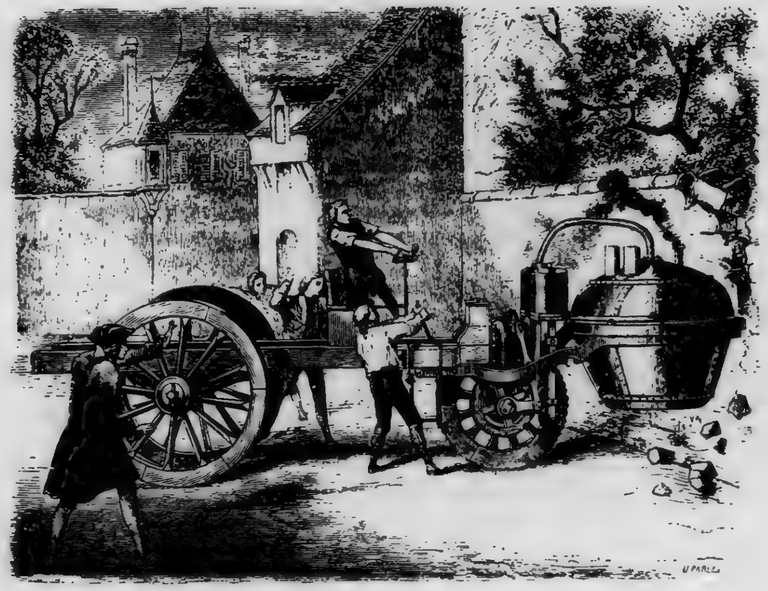


FIG. 49—Cugnot's attempt to drive a gun carriage by steam, 1769.

In the voluminous works of Leupold, published about 1725, is a high pressure engine which is the predecessor of a modern type.

Leupold also depicts a conveyor by which dirt was carried down from a high hill at Dantzig. It consisted of an endless rope passing over wheels above and below a hill, and supported by pulleys along its course. The power was merely a horse and windlass, and the buckets were simply suspended from the rope.

In 1750 Jacques de Vocanson invented a wire band chain together with a cog wheel to run it over, for use in transmission. It was not used to any important extent, but, curiously enough, it was one of the first steps toward a flat belting. In 1782 he also invented a machine for making a flat wire chain. This suggests that one barrier to its introduction had been the cost of production.

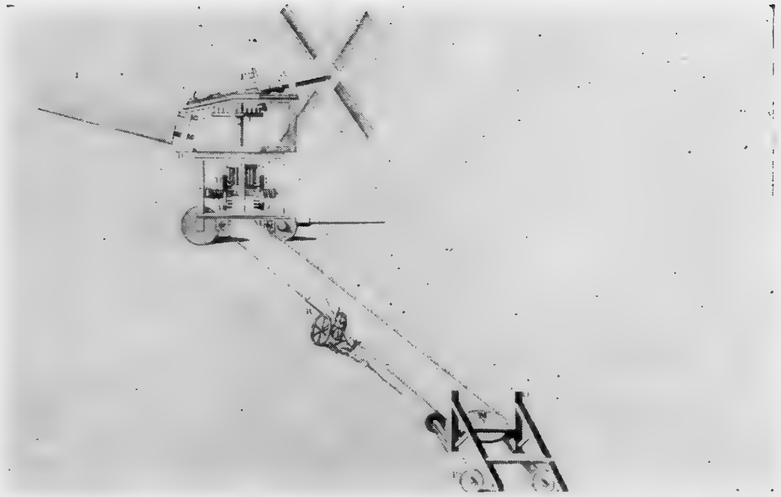
FIG. 50—Methods used in mining, 1770.

THE INDUSTRIAL REVOLUTION

The development of Watt's steam engine, and especially of his Rotary engine, created a demand for toothed wheels able to stand a more rapid movement. This led to the practical use of iron wheels instead of wooden ones.

While a few iron wheels had been experimented with previously, their first general introduction into a factory, was in the Albion Mills, which were fitted out by Watt and John Rennie in 1784. The whole of the wheels and shafts of the Albion Mills were of wrought iron, with the exception of some of the cogs which were of cast iron, and some which were of hard wood. Both of wooden and iron teeth were chipped and filed in an effort to give them the form of epicycloids. The bearings were of brass, and in general the Albion Mills represented the highest type of power and power transmission at the time. They exercised a great influence on subsequent mill work, and may be said to have marked an epoch.

The use of steam power into spinning which began in 1793, and became common in 1808, created a demand for a means of rapid transmission. This demand was increased by the application of steam power to weaving, which became common in the cotton mills between 1815 and 1820, though not in the woolen mills until twenty years afterwards.



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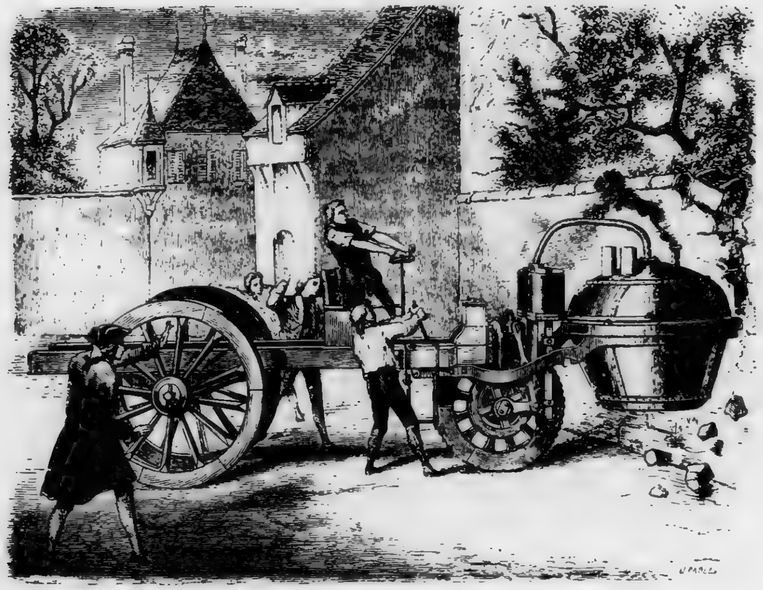

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This gave rise to a modification of the belt. Hitherto belts had been of rope, thongs of rawhide, or of ordinary chains, but the necessity for speed gave rise to the flat belt of leather. No such belts are shown in the French encyclopedias at the end of the 18th Century, nor are they mentioned in English technical dictionaries of that period. They seem to have come in about 1820.

I. H. Beard, writing in 1837, said that he had had only ten years experience with flat belts, which was partly at Lowell and Saco. The situation at that date was summarized by him as follows: 'Until within a few years, it was generally thought that cotton manufactures and woolen manufactures, and all others requiring a very considerable power, could not be run effectively without large and ponderous lines of upright and horizontal shafts of either cast or wrought iron, and heavy trains of cog wheels of cast iron, or partly of iron and partly of wood. And when large leather belts began to be introduced for the main gear of mills, as a substitute for gear wheels, it was thought by some of our best engineers to be an experiment, at least of very doubtful result....Many still adhere to the old mode of gearing."

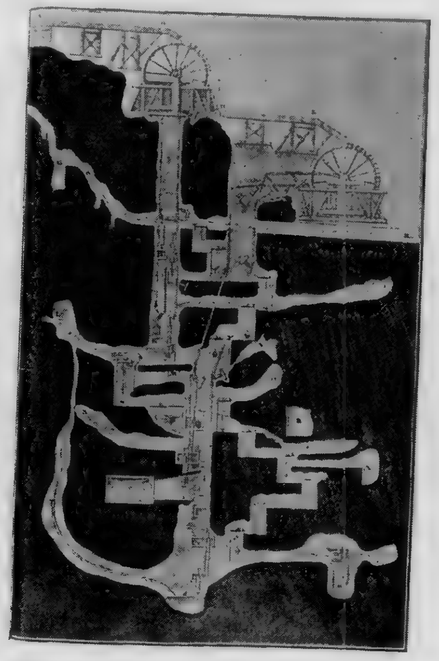

FIG. 51—Pumping arrangements in a mine, end of 18th century.

Dingler's Polytechnik Journal in 1838 stated that flat leather belts had recently been introduced into Germany from America.

Several pictures of English cotton manufactures dated 1835 shows belts in use in carding, or spinning, and weaving. They appear from the pictures to have been stretched tight.

In the United States in 1835 the leather was poorly graded as to thickness, and was merely lapped and sewed. The improvements by currying, stretching, tapering, and cementing the joint, and waterproofing were gradually introduced in the next thirty years.

Though wire rope had been known since the days of the Romans, endless wire ropes used as long belts seem to have been first introduced successfully by Hirn about 1850 at Colmar in Alsace.

FIG. 52—Belt transmission in a cotton mill, 1835.

In 1833 Galle of France invented a linked chain. In this the teeth and the spaces between them were nearly semicircular in form, and the chain was intended to be run with a cog wheel which had cogs of the same shape. Another link belt was invented by Thomas Aveling of England in 1863.

In English coal mines in the first part of the 19th Century, steam power was used for pumping and for hoisting coal up the main shaft, but for little else.

In South Staffordshire, where the veins were about ten yards thick, horses and carts were employed to forward the coal along the galleries to the shaft.

In West Riding, Derbyshire, Colebrook Dale, Lancanshire, and other places, the seams were often less than thirty inches thick. In West Riding children, including girls as well as boys, were kept at work pushing the small oblong carts along the rails in the low galleries, and sometimes in picking the coal. The galleries were not high enough for even such children to stand up, and they had to crawl along on their hands and feet.

In Derbyshire both boys holed and picked the coal, after which it was hurried, as it was called, by children who had belts around their bodies, and connected by chains with the carts.

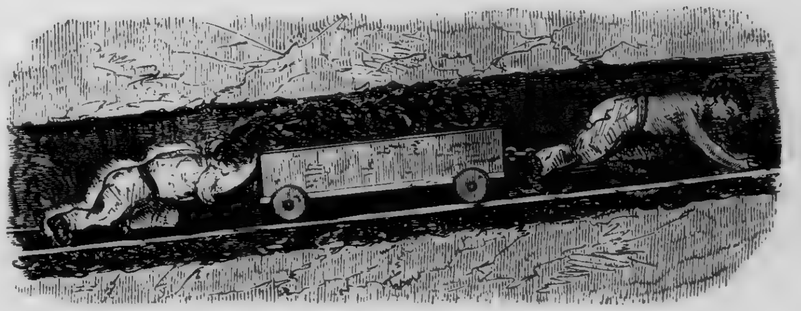

FIG. 53—"Hurrying" coal in a thin seam mine. England, before 1840.

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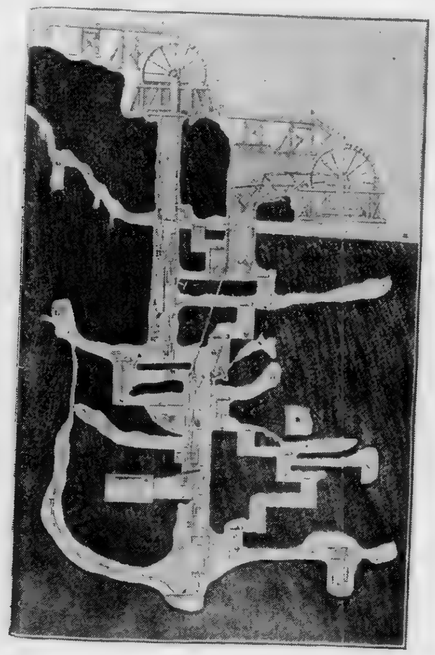

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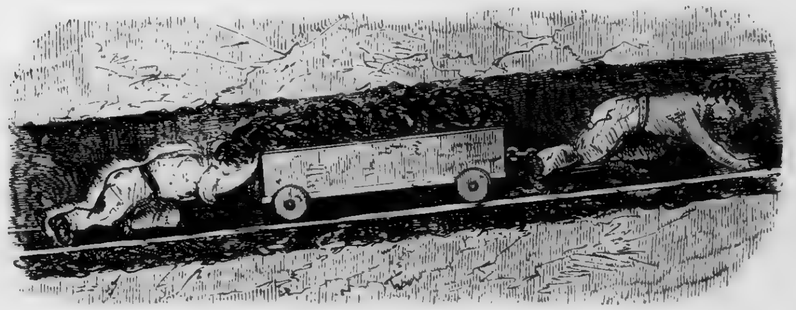


FIG. 53—"Hurrying" coal in a thin seam mine. England, before 1840.

In Scotland girls and women carried the coal along several levels, and up several ladders, to the tub where it was drawn up the shaft by steam. They worked with baskets on their backs, which were steadied by straps running around their foreheads. In those mines girls assisted in trapping and bearing coal, and in pumping water, and hewing wood.

In Pembroke, however, the coal was drawn up inclines by means of windlasses which were worked by women.

The gradual development of machinery made much of this work unnecessary and, in 1843 a law was passed, first that no female under eighteen, and then none at all, should be employed in the mines. At the same time it was forbidden that any boy under ten should be received as an apprentice, or kept as one for more than eight years.

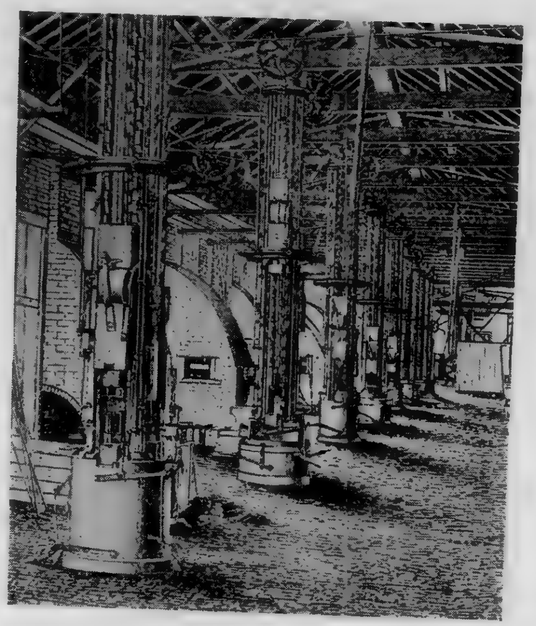


FIG. 54—A forging room of 1850, with compound crank drop forges.

The history of the development of power in America is full of tragedy. Many chapters could be written of the triumph of the early colonies and the determined men overcoming tremendous hazards and obstacles without equipment or tools except those they hewed and mined and quarried by hand, all hauling by hand, oxen, or boat. It begins in the sixteenth Century with iron ore found by Sir Walter Raleigh in North Carolina, later the first iron works was started about 1620 by John Berkeley, in Virginia on Falling Creek, a tributary of the James river, which continued successfully until the plant was destroyed and all the workers with their families being masacred by the indians. Space only permits us to mention the following of the early pioners who were workers of iron and steel. John Winthrop, Governor of Connecticut, in 1645 built the first iron works of New England at Lynn, Mass. with a later furnace and forge at Baintree, Mass. As success followed both efforts, in 1658 another furnace and forge was established at New Haven, Conn.

The first plant in New Jersey was started at Tinton Falls, with another at Hanover about 1710 by Henry Leonard.

About the same time Geo. Ryerson established a furnace and forge in northern New Jersey, with Governor Alexander Spotswood establishing smelting furnaces for the Appalachian Mountain ore in Virginia. The first furnace and forge in Delaware

was established in 1726 by William Keith. The first iron works in New York was in Columbia County built in 1741 by Philip Livingston, signer of the Declaration of Independence. The continual bickering and strife of the colonist with the British manufacturers and with the operation of the Durham furnace, an old fashioned bloomery mill, beginning about 1750, in Bucks County, Penn. to manufacture the heating and cooking stove to which Benjamin Franklin, who signed the Declaration of Independence, added improvements. The acts of the British Parliament finally led to the Declaration of Independence and this furnace commenced manufacturing cannons, cannon balls and iron for the Revolutionists.

Among the signers of the Declaration of Independence we find Geo Taylor of the above Durham furnace.

Stephen Hopkins, Governor of Rhode Island, interested in Hope Furnace of Rhode Island.

James Smith owner of Cadorns Forge, York County, Pa.

George Ross, interested in Mary Ann Furnace, Lancaster, Pa.

It is also notable that Augustine Washington, father of George Washington built the Accokeek furnace on the Rappahanock River, Stafford County, Va., for ore supplied from the Washington plantation and George Washington thus became familiar and interested in the manufacture of iron.

The modern era of the iron industry in the U. S. begins in 1848 with the discovery of Iron ore in great bodies on the upper pensula of Michigan.

The developments in the second half of the 19th Century were not only revolutionary in character, but came in quick succession.

The first important practical transmission of power by compressed air, was for drilling at the Mount Cenis tunnel in 1861. The drills, by the way, were built after the designs patented by Fowle in the United States about 1850.

In 1856 Combe of Belfast employed several ropes to run in grooves on one pulley, and used such grooved pulleys for distributing the power.

Lord Armstrong in 1846 had erected an hydraulic crane at Newcastle, which was run from the water mains, though the pressure was found unsatisfactory. In 1877, however, a public hydraulic supply station for power was established at Hull, which has been successful.

In 1873 Brayton, in America, invented a light oil engine with constant pressure but without explosion. Otto's gas engine dates from 1876. In 1883 Daimler succeeded in developing a small high speed petrol engine, which in 1886 he applied to a motorcycle, and in the next year to a motorcar.

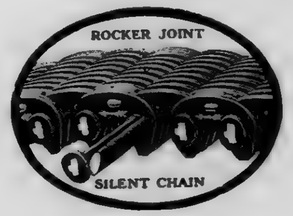
The Parson's compound turbine dates from 1884, and the turbine of de Lavel from five years later.

The electric motor had its beginning in the Vienna Exposition in 1873, when it was discovered that either of two dynamo machines of the Gramme type, could be set in motion by the other. The electric street car dates from 1881.

A long distance transmission of electric power was successfully begun at Frankfort in 1881, and developed at Niagara ten years later.

All of these epoch making inventions in prime movers, and their applications to machines, created revolutionary demands in power transmission. In one way or another these involved the transmission of great power, at a controlled and often high speed, in a small space, and without noise.

This has led to what might be considered combinations of steel link belts and sprockets. The Rocker Joint of these so-called silent chains was invented by Morse in 1901.



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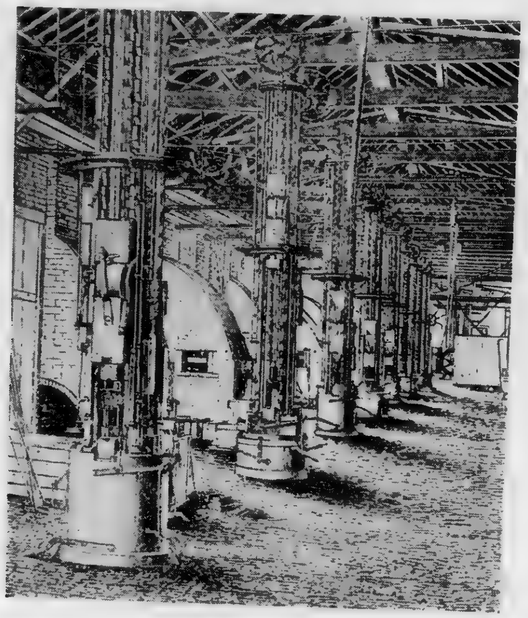

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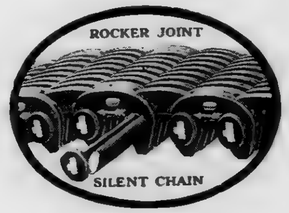

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Chain driving would be classified under tooth gearing, and has among the characteristics of its class, the fixed speed ratio, since it is driven by the contact of a third jointed link member with the teeth; and has a bearing pressure which varies almost directly with the power transmitted. When the Silent chain was introduced, this, through its elasticity and peculiar method of contact with the sprocket teeth, formed an elastic medium that absorbed the variation in angular velocity and shocks found in many gear, and in the old form of chain, transmissions, and produced an elastic bearing action quite similar to that when driving with belts.

Ventilating Fan Driven by Morse Chains

Unlike gearing and other devices in its class which call for fixed pitch centers, the chain permits of varying center distances within a reasonable range the same as belting, and this makes its application most convenient.

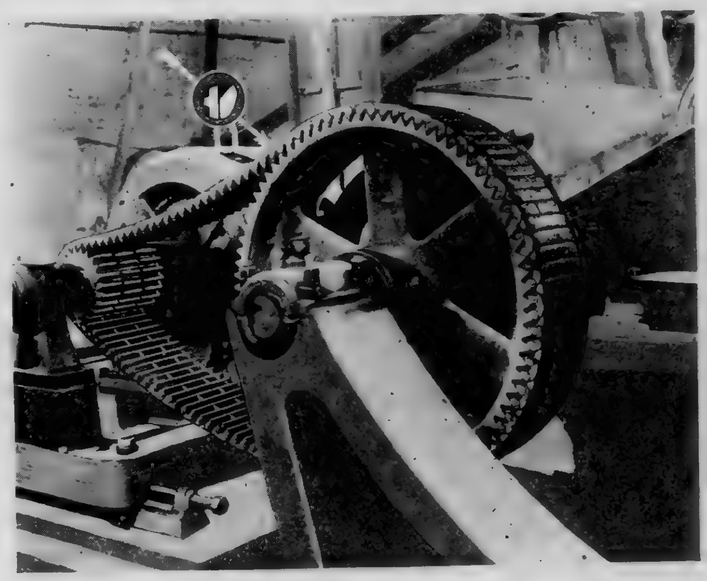
There is little importance in bringing to the attention of the gentlemen here present the limitations of gearing, as you probably are more familiar with that method of power transmission than I am. Suffice it to say that the gear drives through sliding friction of tooth against tooth, and to obtain uniform angular velocity, theoretically correct center distances, tooth form and tooth spacing are necessary. These necessities call for refinements in manufacture that are not generally obtained, and anything materially short of perfection decreases the efficiency and increases the noise of the drive.

There is another point that might be added, which is found very largely in transmission gears on automobile engines where the gears are made from high grade alloy steels and then hardened. In this hardening process such gears are slightly deformed, and in addition internal stresses are set up so that the gear is eccentrically toned independent of its being physically eccentric, and so will

produce even when physically as true as a gear grinding machine can make it, the same objectionable, intermittent howl that is found in a gear when it is eccentric. Possibly it is to this eccentrically toned quality of gearing more than to any other one thing that the substitution of Silent chain for this type of drive is in the automobile is due.

The improved Silent chain is made of stamped arched shaped links inherently possessing a certain amount of elasticity, and is thus driving through an elastic medium without shock or objectionable noise, which makes it most desirable for general power transmission purposes.

The chain when assembled may be considered a flexible rack, and due to this fact we have coined the word "flexible gear" as best describing it. The internally projecting tooth of the link plates engages the sprocket wheels over a considerable arc of their circumference, and thus the pressure per tooth is much less than that found in gearing. Again the sliding contact under the heavy pressure of driving that exists with gearing does not exist with the chain. For these reasons, and also



One of many Morse Chains giving unusual service. Bradford Brick & Tile Co.

because the contact is with a large number of teeth each of which bears its share of the burden necessary to drive, tooth wear is practically eliminated in a properly designed chain drive.

The link engagement with the tooth is at a point below the line of pull so that in a small driving sprocket where the angle of tooth to the line of pull may sometimes be less than the angle of friction, there exists in addition to any centrifugal force that may exist, a lever action that tends to maintain the chain at a point higher than its proper pitch. When there are above twenty teeth in the sprocket the contact with the tooth is at an angle greater than the angle of friction, which tends to make the links slide up the teeth, and this tendency for the chain to take a larger pitch diameter on the sprocket wheel automatically compensates for the lengthening of the chain, and maintains a correct pitch relation between the chain and the teeth of the wheel.

There are three forces which tend to slip the chain outwardly and over the teeth, requiring a definite opposing force to keep it in place. A large part of this accumulative restraining force is represented by the frictional resistance to sliding up the teeth, which depends on the number of links in engagement, as well as on the size of the sprocket, since the force varies with different size wheels. Experiments

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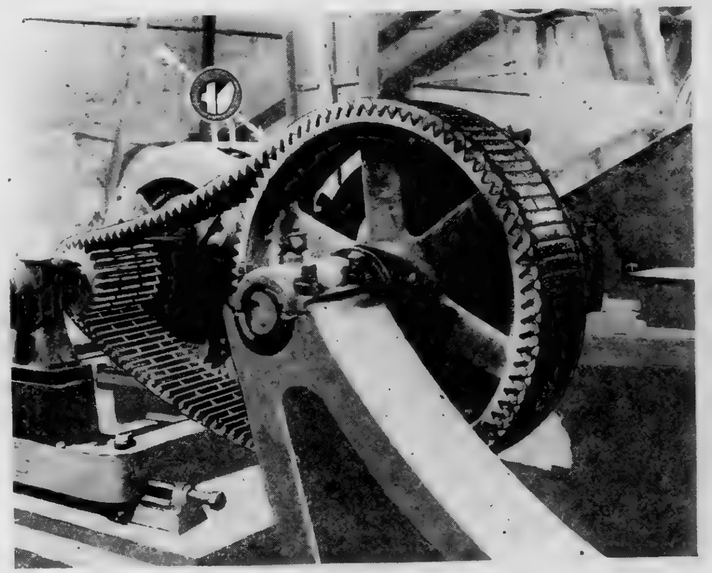

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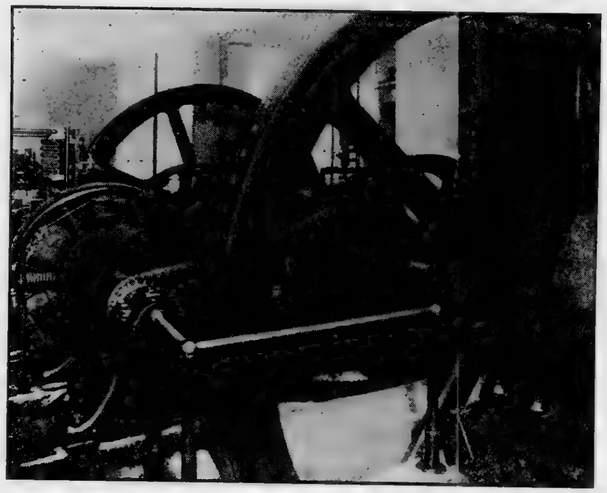
have shown that from five to thirty teeth in engagement, depending on the angle of tooth to the line of pull, are sufficient to keep the link farthest away from the direction of pull from raising on the tooth with any appreciable force.

[The number of teeth in the wheels can be reduced so that all except the first tooth engage with less than the angle of friction, but under these conditions the drive does not operate quietly or in accordance with the general design of Silent chain.]

In a proper design, say with five or more teeth engaging, before leaving the driving sprocket the chain will float between the teeth, not touching either face, until the tension on the slack side pulls the chain against the idle or non-driving face of the teeth. As in belting, the effective driving force of the chain is the difference between the tight and slack strands, and something of the same "creep" that is found in belting takes place on the tooth faces, since the chain is driving through frictional contact with many teeth. Unlike belting, however, the chain drive still gives a positive speed ratio because either by friction against the teeth or by tension on the slack side, or both, it is prevented from going over the top of the teeth, while it still drives through frictional contact with many teeth without getting out of the proper tooth relation.

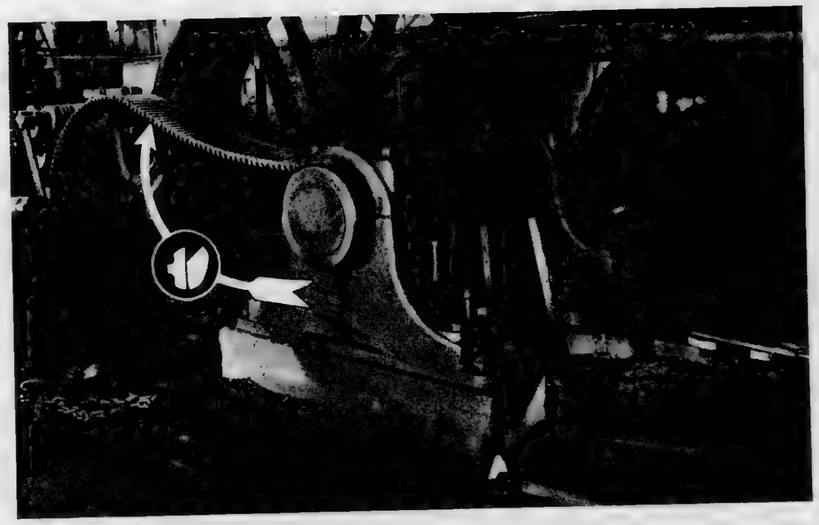


Morse Chains Driving Compressor

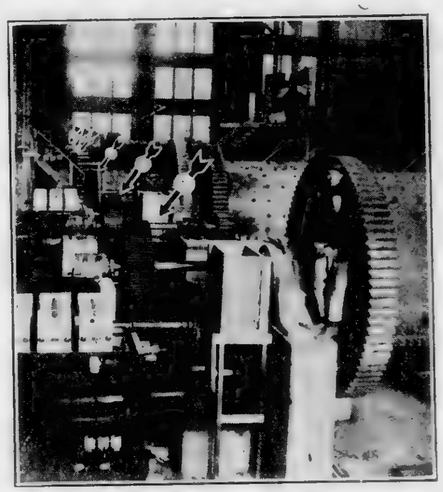
On the driving wheel the first or entering link engages with the tooth when moving in nearly the same direction and speed as the sprocket, and takes up its burden of driving with little shock or noise. The first link engaging takes the largest share of the burden of driving, and, due to elasticity, is longest at this point, and rides highest on the sprocket tooth.

The lengthening of the chain links, due to elasticity, decreases progressively around the wheel, and this permits the chain to creep down the teeth of the driving wheel, until it reaches a point at or below its pitch diameter. Under these conditions the chain is drawing a spiral on the sprocket, with the larger diameter on the driver at the entering tooth and on the driven at the leaving tooth, while somewhere between, where the tension on the slack side becomes operative, will be found the smaller diameter. It is this distribution of tension necessary to drive over a larger number of teeth that causes the chain to be quiet in action, since the pressure of driving is taken up gradually and without blow effect.

In the Silent chain on the market today there are two forms of joint practically distinct from each other, the sliding friction joint common to all chains except the Morse, and the rocker or rolling friction joint of the Morse chain. In the rocker joint the bearing consists of two joint pins each securely anchored in opposite



Simmons Company. 500 H. P. Morse Chains driving rolling mill rerolling railroad rails.



Morse Chains Driving 5′ x 20′ Tube Mills
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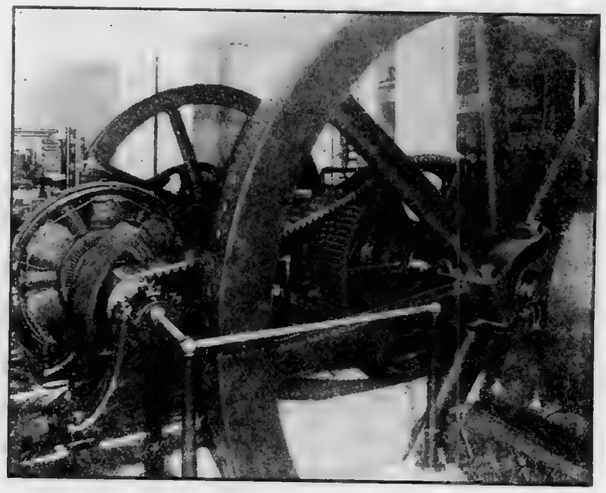

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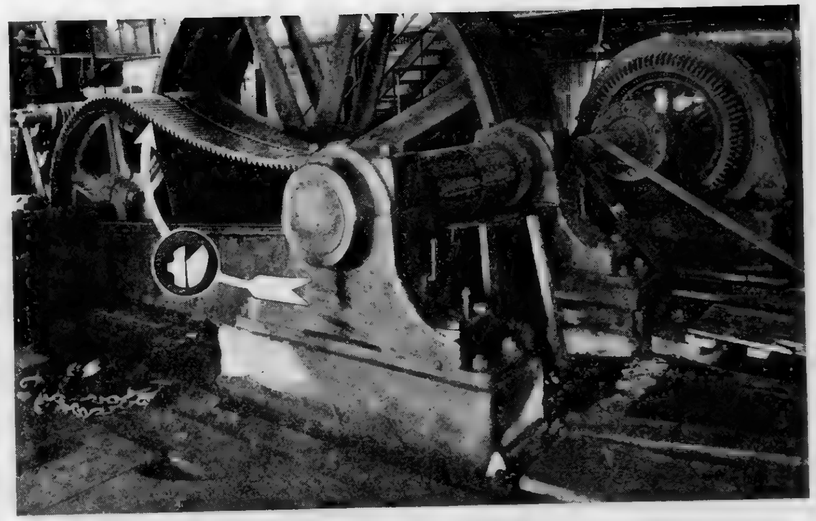

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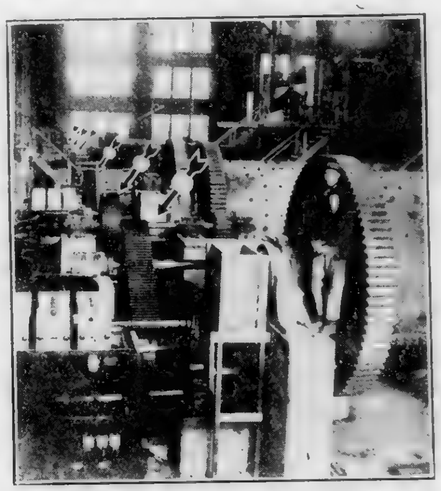

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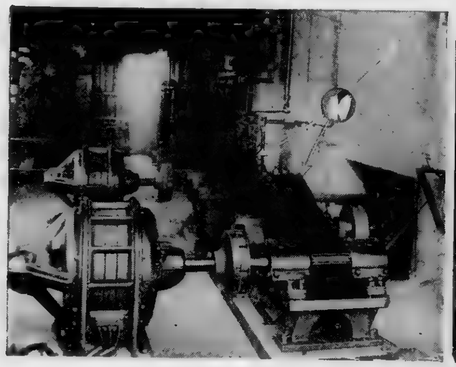
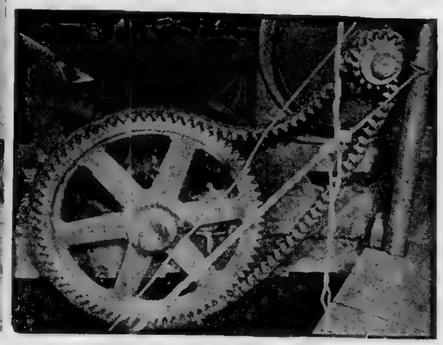
ends of each link, and so shaped and arranged as to provide a rolling motion when the joint is worked, and a broad, flat bearing surface to take the tension of the tight strand between the wheels. The apertures in the links are shaped so as to provide a clearance for the joint pin, which is a part of the opposite leading link, and to permit of a free rolling action of one joint member with another.

The substitution of rolling instead of the common sliding friction in the chain bearings or joints has eliminated the necessity of continuous lubrication, and decreased the joint friction to a minimum, besides adding materially to the life of the drive when run dry or in the presence of grit or dust. The importance of this construction is emphasized when it is understood that the sum of the angular motions of the joints on the tight side of the chain alone, and under nearly the same pressure as the shaft bearings carry, equals the combined angular motions of these shafts. Think of the motor bearing, its size, provision for lubrication, and, if you then compare it with the bearings in the chain links, there should be no surprise if sometimes the chain fails; but as a whole it is efficient, quiet and durable, with a life of from three to fifteen years.

The small sprocket as a rule is made of steel hardened, the large of a close-grained cast iron. The shrinking or pressing of the wheels on their shafts so often essential with gearing on account of the single tooth engagement of metal to metal worrying the gears loose, is not found necessary with the silent chain where the forces are more like a belt. This makes the application of a chain drive almost as convenient as as a belt.



Morse Chain Driving Rolls, Dominion Iron & Steel Co.

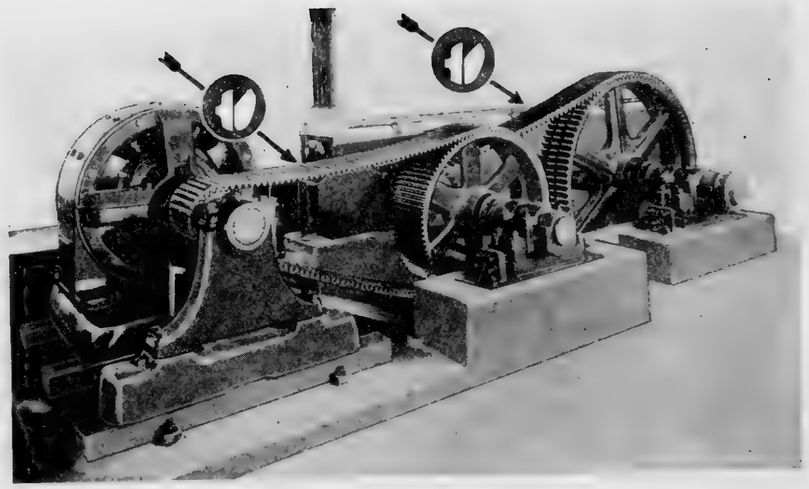


Morse Chain Driving Head of Rock Flevator

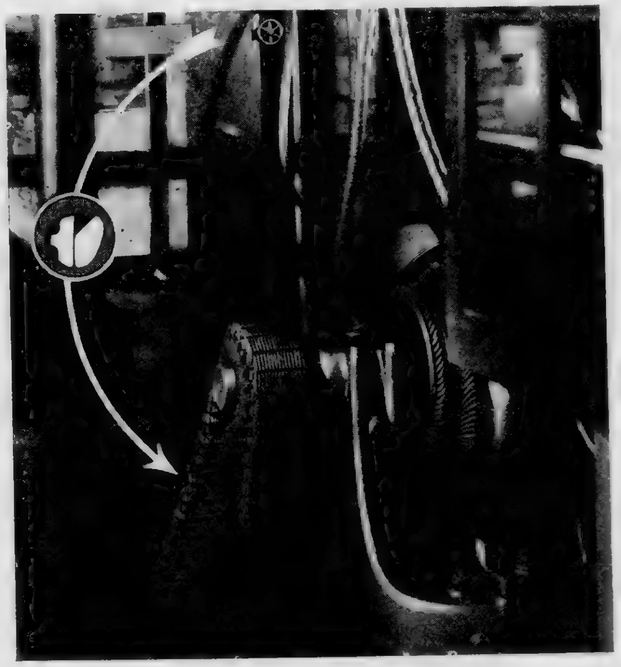
The lasting quality of the Silent chain drive is commercially satisfactory as evidenced by the large and continuous increase in its use. We alone have sold over 3,500,000 HP in chain drives since 1903, and at a present rate of over 500,000 HP per year, so that it is considered a standard form of power transmission, and should be preferred from an efficiency standpoint where short centers are necessary or desirable, where a positive speed ratio is required, where heat or dampness would prevent the use of a belt, or where gears would make an objectionable noise.

The American Machinist writing editorially on Nov. 24th, 1910, says:

"It is characteristic of present-day progress when developments are taking place in so many directions that individual developments fail to attract general attention until they have reached a point which is fairly startling, a case in point being the use of silent chains for the transmission of large amounts of power. It is the bicycle that thanks must be given for the impetus which led to the present developments in chain driving, bicycle chains having been the first in which high-class workmanship was adopted. Good chains having been made for bicycle use, other applications were naturally found for them, although naturally for moderate amounts of power. It is certainly a far cry from the bicycle chain to a drive which transmits 1,000 horsepower, and yet it is to this figure that chain driving has now come.



Raymond Lead Company. Thirteen years driving Reversing Lead Rolling Mill without a repair.



Dixon's Crucible Chain Drives. 15 years' operation at practically no expense.

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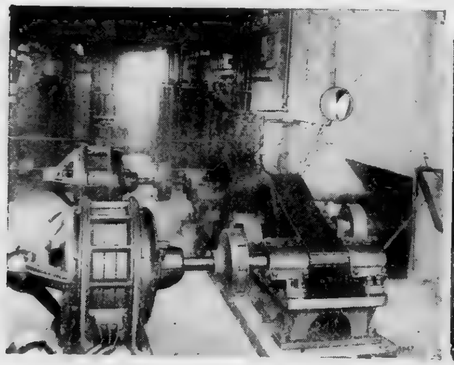

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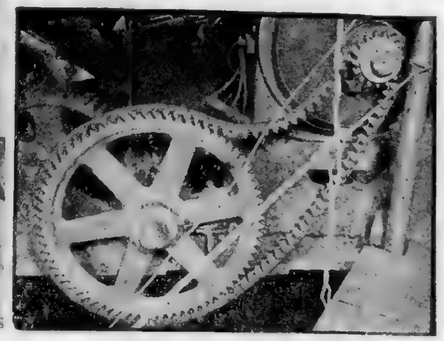

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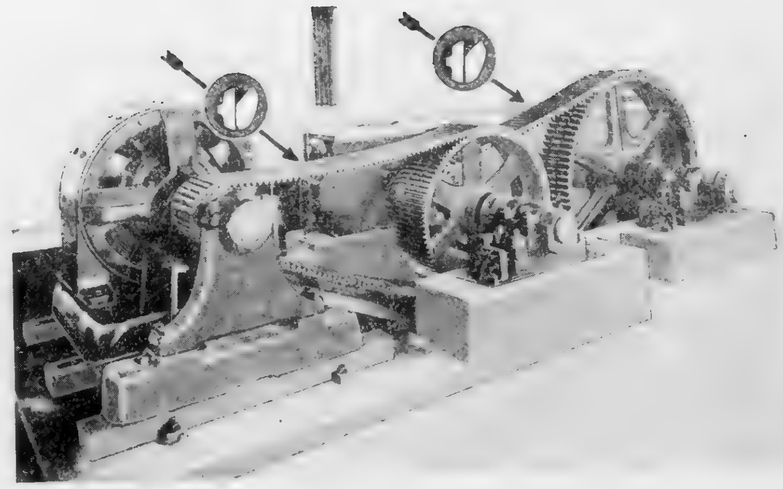

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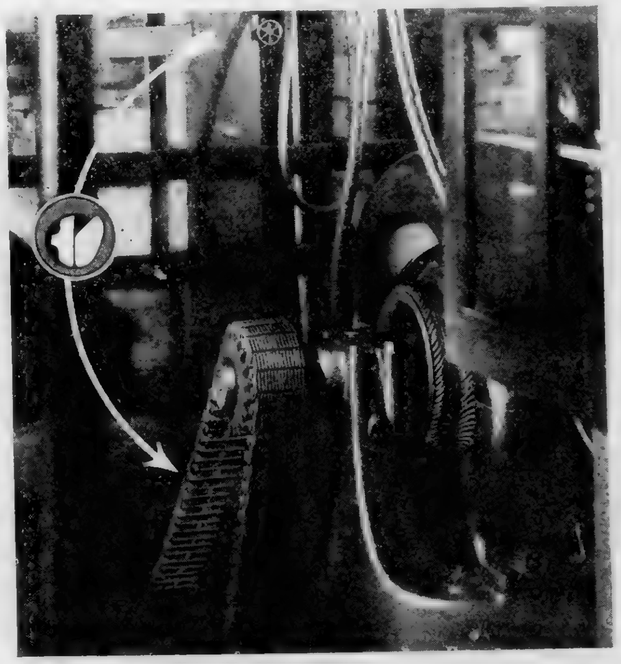

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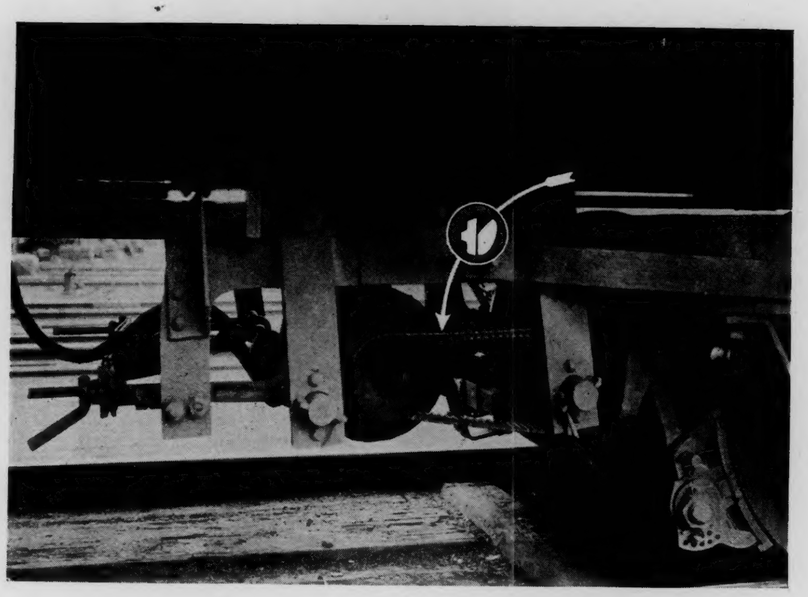


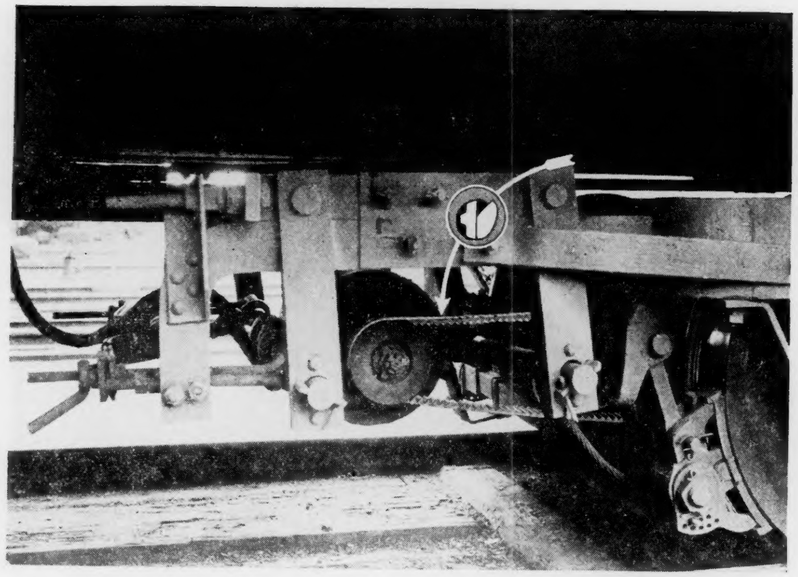
Morse Chains driving Generator for Lighting Passenger Cars.

"While these figures represent the maximum accomplishment, they do not include the only one which is noteworthy, there being in operation in this country not less than two hundred chain drives transmitting from 100 to 1000 horsepower each.

"Except as gears have occupied the field, the chain drive opens up new possibilities in the matter of compactness, When ropes or belts are used, considerable center distances are a necessity, and when large center distances are required the conditions indicate a drive by belts or ropes. In many cases, however, short center distances would be used were it not that belt or rope driving requires long ones. The fact that short center distances are available frequently reduces the dimensions of buildings which ropes or belts would require and thus leads to a large indirect saving. In the case of Figure 3, the location of the shafts being fixed, a preliminary layout of a rope transmission was made, the result being a three-story building to provide the necessary center distances and accommodate the intermediate sheaves and tension carriage—the whole arrangement being nothing less than formidable. Short center distances provide the natural field for chain drives, their only competitor for such case being gears. In the matter of cost, chains are more expensive than gears, but against this, tests concur in showing a higher efficiency for the chains, which, in plants of the magnitude shown, leads to a constant saving of enough importance of justify placing it against the greater initial cost."

This was prophetic of the high speed chain development, and we believe that it can be justly claimed that today it holds its place as a power transmitter equal to any and superior to most, for the transmission of power from motors to the driven units.

It has taken a considerable period of time to obtain the illustrations used in this article and the work is only commenced. The writer will greatly appreciate photographs or references to ancient devices, especially those relative to early developments in the United States



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"While these figures represent the maximum accomplishment, they do not include the only one which is noteworthy, there being in operation in this country not less than two hundred chain drives transmitting from 100 to 1000 horsepower each.

"Except as gears have occupied the field, the chain drive opens up new possibilities in the matter of compactness, When ropes or belts are used, considerable center distances are a necessity, and when large center distances are required the conditions indicate a drive by belts or ropes. In many cases, however, short center distances would be used were it not that belt or rope driving requires long ones. The fact that short center distances are available frequently reduces the dimensions of buildings which ropes or belts would require and thus leads to a large indirect saving. In the case of Figure 3, the location of the shafts being fixed, a preliminary layout of a rope transmission was made, the result being a three-story building to provide the necessary center distances and accommodate the intermediate sheaves and tension carriage—the whole arrangement being nothing less than formidable. Short center distances provide the natural field for chain drives, their only competitor for such case being gears. In the matter of cost, chains are more expensive than gears, but against this, tests concur in showing a higher efficiency for the chains, which, in plants of the magnitude shown, leads to a constant saving of enough importance of justify placing it against the greater initial cost."

This was prophetic of the high speed chain development, and we believe that it can be justly claimed that today it holds its place as a power transmitter equal to any and superior to most, for the transmission of power from motors to the driven units.

It has taken a considerable period of time to obtain the illustrations used in this article and the work is only commenced. The writer will greatly appreciate photographs or references to ancient devices, especially those relative to early developments in the United States

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